TOTAL LIFE CYCLE COST

IN THE CONSTRUCTION INDUSTRY

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by

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Finally, the author dedicates this humble piece of work to his wife, Irina.

ABSTRACT

The purpose of this study is to develop the concept of total life cycle costing technique for project investment appraisal in the construction industry. This technique incorporates initial investment costs, future cost and other non quantifiable aspects in monetary terms of the project. A spreadsheet programme is used to analyse projects and by applying this technique a sensitivity analysis can be performed.

Alternative bridge project types and alternative road project options have been analysed using the the total life cycle costing technique. The results indicate that the concept of total life cycle costing together with sensitivity analysis facilitate an effective choice from a number of alternative options.

The results of this study have demonstrated the usefulness of the concept as s decision-making tool and its application to projects in the construction industry.

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CHAPTER ONE

INTRODUCTION TO LIFE CYCLE COSTING TECHNIQUE

1.1 THE PROBLEM

Decisions in the construction industry have traditionally been based on a comparison of initial capital costs. All other costs were considered to be unimportant and could therefore be ignored. It was argued that, since capital cost is of paramount importance, the lowest capital cost option will also be the lowest total cost option. The reason for basing projects on such concepts was that it was easier to predict the initial costs at an early stage than the longer term costs. However, these longer term costs can by far outweigh initial costs, and can significantly affect the decision based on the lowest initial cost concept.

It is therefore important to devise a method that incorporates both the initial and future costs of an asset in its economic analysis. In this study the life cycle costing technique has been adopted as it has the means to fulfil this requirement. The life cycle cost technique is particularly relevant to the proper identification and evaluation of the cost of a durable asset.

The central problem in adopting the life cycle cost approach is to reduce to a common base cash flow expenditures and receipts that arise at different points in time. For example, future costs incurred at varying points during the subsequent operation of the project cannot be treated identically. This is due to the fact that money today is not equivalent to money tomorrow. A life cycle cost approach must have, as a central feature, the presentation of current and future costs in equivalent terms.

Another problem associated with life cycle costing is the fact that it deals with future costs and future costs are hard to predict with certainty. Because of the risk and uncertainty inherent in some of its components, a sensitivity analysis technique is applied to life cycle costing to reduce the risk involved.

1.2 OUTLINE OF RESEARCH

It is important at this stage to try to fully develop the concept of life cycle costing and be able to apply it in the construction industry. The aim in this study is to explain and illustrate the techniques used in life cycle costing. In addition, a simple method of cost analysis is presented, using a VP-Planner package, to carry out the life cycle cost analysis of projects in chapter 4.

This package was adopted as it enables the user to perform a sensitivity analysis; a univariate approach that identifies the impact of a change in a single parameter value.

Projects with a long service life were taken for analysis, for example, bridges and roads as these projects comply well with the concept of life cycle costing because of their long service lives. Alternative options for each of these projects were considered to facilitate comparison and the choice of the best option from the alternatives. The relevant calculations of the projects considered for analysis in this study are shown in the Appendices.

CHAPTER TWO

BACKGROUND LITERATURE

2.1 INTRODUCTION

This section presents a review of a recently new method of project evaluation in the construction industry. This concept deals with the life cycle costing of projects by assessing the total cost of a potential construction project over a given study period. Strictly defined, life cycle costing (LCC) of a project is simply the sum in present value terms of all costs and income associated with that project. The LCC method of analysis is used to compare the life cycle costs of alternative projects so as to be able to choose the least costly, i.e. the most cost effective.

2.2 APPROACHES

BROMILOW AND PAWSEY, (1987), [2] emphasized the role of LCC in the management of buildings, and in particular emphasized its importance in maintenance and rehabilitation. In their work they addressed in particular the question of the construction of a maintenance programme and the identification of optimal replacement periods. One good example analysed by the authors raised the important question of how to fund the LCC programme. They showed that if 1.1% of building's costs were invested in a sinking fund this would be sufficient to fund the building's needs indefinitely. Such results are really important to the owner or users, however, they are unacceptable to decision makers as they leave little scope for managerial discretion.

BIRD, (1987), [2] addressed the problems of data limitations in life cycle costing. The author recognised the lack of feedback that is currently available to owners or users of buildings about the running cost of their buildings. Emphasis was put on a systematic data collection which is related to the required performance of the building. Performance was deemed to be of particular importance. The author argued that there is not necessarily a connection between initial procurement costs and future operating costs.

However, FLANAGAN and NORMAN, (1983), believed that such a relationship existed. They were of the opinion that higher initial costs may significantly reduce future operating costs and that capital and future running costs are intimately linked and should not be treated separately. Bird suggested that such a connection is only likely to emerge if the choices of designs are related to a defined quality and performance. The problem still remains that data on existing building are unlikely to give any such relationship precisely. The reason for this is that these data are not related to performance so a structured data base is essential.

JOHNSON, AHMED, SHERIF and BECKER, (1987), [2] point to the idea that qualitative considerations are of considerable importance in building design. LCC does not of itself include considerations such as the impact of good design, or efficient building performance, on productivity, job retention and the ability to attract good staff. Such considerations are important when looking at a construction project, be it a university research laboratory as it was with this paper, or a commercial building or factory. There is a direct relationship between the university spending on its science facilities and its ability to generate funds as a consequence of its reputation. It is quite possible to think of a relationship which would equally apply to any construction project. What is rather more imaginative is to see how these considerations can be built into initial design decisions. The LCC lends itself precisely to such issues. LCC analysis has value primarily as a tool to help facilitate design and management decisions. However, the effective use of LCC analysis was limited in this work because of the importance of the non-economic qualitative policy considerations.

MARSHALL, (1987), [2] discussed building economics in the United States and considered alternative appraisal techniques within the broad context of LCC. The common characteristic of all the methods was that they all consider benefits (savings) and costs over the project's life cycle or study period. He recommended eight steps for economic evaluation:

(a) Identify objectives. This requires that the objective achieves a certain level of performance in a cost effective manner.

(b) Identify constraints.

(c) Identify choices.

(d) Estimate relevant costs and savings.

(e) Adjust costs and savings for time differences.

(f) Calculate measures of economic performance.

(g) Compare alternatives.

(h) Perform sensitivity analysis.

The problems associated with the application of building economics methods here were availability of data, uncertainty and attitudes. Means of approaches for dealing with uncertainty were suggested and these included sensitivity analysis, expected value analysis, required short payback periods, and raising discount rates to adjust for risk.

FLANAGAN, KENDELL, NORMAN and ROBINSON, (1987), [2] addressed the problem of risk and uncertainty that are inherent in any LCC calculation. LCC deals with the future and has to make assumptions about future costs, expected lives of materials, and so on. In fact this has led many critics of LCC to reject the technique as being fundamentally inaccurate or based on guess-work. Such a criticism was viewed by the authors as a misconception; what is more appropriate is to use the risk and uncertainty to guide decision making rather than to pretend it does not exist by basing decisions on initial costs only. For this to be possible, it requires that a risk management system be incorporated with a life cycle costing system. It was argued that a decision based on initial capital costs is likely to be more susceptible to risk than a decision based on precise life cycle costs because the former criterion ignores risk. This paper discussed how such a risk management system would fit, described the features it should exhibit and illustrated how the results of a risk analysis might be presented.

A feature that clearly emerges from this study is that LCC and risk analysis cannot be used as a substitute for managerial decision making. Instead, they serve as powerful tools that can be used to tremendously improve the quality of decisions.

WALLACE, (1987), [2] highlighted some of the hurdles that LCC still has to overcome. The underlying methodology is of considerable interest, relying as it does upon direct observation of the design team. The results show an interesting cross-over in discussions of capital costs versus costs-in-use. As the design process continued the design team became increasingly preoccupied with initial costs; much of this preoccupation was client driven. The central message which emerged was that considerable work remains to be done in persuading clients of the economic efficiency that will arise from striking an effective balance between initial capital costs and future operating costs, i.e, to form an effective use of life cycle costing.

TIETZ, (1987), and SOMERVILLE, (ENG. 1986), stressed the importance of assessing and cost forecasting at design stage the significant elements that are likely to influence the running costs. They pointed out that factors that make up the total life costs of projects are mostly influenced by the initial design. For example, the energy a building will use depends on the plant installed and the amount of insulation just as the cleaning bill is directly related to the materials used for finishes. They referred to life cycle costing as a collective title for a whole range of techniques, each appropriate for a different use. This shows it is important to identify what is to be established. A choice can be between different components, say a cladding with a 20-year life as against a more expensive one lasting longer, or a floor which needs constant waxing compared to a carpet. Thus, the proposed life of a project is critical to the calculations and probably the client can best determine what he anticipates. Furthermore, the discounted cashflow method was considered more viable for long term periods, than for capital cost or running costs in the short term. Both authors viewed life cycle costing as a design tool which required the attention of engineers as well as the decision makers. For example, an engineer choosing a concrete mix to use in a particular building should know the anticipated life of the structure and its performance.

STONE, (1967), pointed out that a relationship exits between initial costs and future costs of any project, say a building. Cost-in-use technique was developed to provide a means of comparing building design and planning alternatives to a given end and to obtain the best value for money for the resources spent. Therefore, the concept of cost-in-use is to provide a way of evaluating both the the initial costs of a project and its costs throughout its life. As this method incorporates future costs in its evaluation, there are risks involved in it, since the future can never be known for certain. When using this method, prediction errors must be considered. Further still, scarcity of information on past and existing buildings hampers precise forecasting of future costs.

It was pointed out that elements which are common should be eliminated. Similarly, for a comparison of the alternative designs for any particular functional group of a building or groups of elements which do not interact with the group considered can be eliminated from the design comparison.

WATANALADA et al, (1987), working under the World Bank developed a whole Life Cost model. The Highway Design and Maintenance Model (HDM-III) was developed to meet the needs of highway authorities for evaluating policies, standards and programs of road construction and maintenance, particularly in developing countries. In producing a total life cycle cost for a given highway design and maintenance option, the program incorporates pavement construction costs, deterioration/maintenance costs and vehicle operating costs. The program facilitates a quick investigation of the life cycle of a single road (or network of roads) under a variety of traffic and maintenance options, allowing comparisons between the economic effects of different maintenance policies. In addition to comparing alternatives, the model can analyze the sensitivity of the results to changes in assumptions.
Limitations of the model are:

1. The submodel for calculating vehicle operating costs does not include the effects of congested traffic conditions.

2. The road deterioration submodel does not include the effects which specifically apply in freezing climates, nor does it encompass rigid pavements.

3. The model does not account for the effect of varying basic routine maintenance on pavement performance.

4. The model does not endogenously predict road accidents or their costs, nor environmental impact, nor traffic delay costs during road construction and maintenance.

2.3 ASPECTS OF LCC

Table 2.1 shows the authors who have reported work on LCC and the aspects each individual discussed. The aspects considered are:

(i) A = Performance
(ii) B = Management tool
(iii) C = Data limitation
(iv) D = Methodology
(v) E = Relationship between capital and future costs
(vi) F = Risk and uncertainty
(vii) G = Attitudes
(viii) H = Future costs
(ix) I = Life of components
(x) J = Discount rate

The asterisks (*) indicate the aspects considered by the authors.

Table 2.1: Aspects Discussed by Various Authors

	ASPECTS									
AUTHORS	A	B	C	D	E	F	G	H	I	J
Bromilow & Pawsey		*	*	*						
Bird	*		*			*		*		
Flanagan & Norman			*			*				*
Johnson	*	*				*		*		*
Marshall	*	*	*			*	*			
Flanagan et al	*		*		*	*	*			*
Wallace							*	*		
Tietz & Sommerville			*		*	*	*		*	*
Stone					*	*			*	*
Watanalada et al	*	*	*	*		*			*	*

2.3.1 Performance

Performance of buildings or completed civil engineering projects have not been given great consideration when assessing the total life cycle costing of a project. Some of the major reasons are; first and foremost, the designers are in no way obliged to be explicit about the attributes of the projects they design in performance terms, nor do customers state explicitly the required performance. Secondly, absence of performance data together with a mechanism for providing regular feedback are held to be major barriers to life cycle costs. Thirdly, the risk of legal action deters manufacturers from grading the performance of their products, or stating explicitly how they may be expected to perform once incorporated into a building or project, or what factors will effect their expected life. To make such statements might increase the risk of an action being brought against them in court. What is required to overcome this problem is to have an agreement between the client or designer and the manufacturer to provide all the necessary information required to predict performance without fear of prosecution. This will facilitate prediction of the performance of components and indicate when replacement and maintenance should occur.

2.3.2 Managerial Tool

LCC has been viewed as one of many methods of economic evaluation that considers all relevant costs associated with a project during its life. However, the idea that it is a potential managerial tool has not yet gained popularity amongst decision makers. The reasons are related to uncertainty and attitudes. LCC is dealing with future costs and the future is full of uncertainty. Some attitudes reflect a reluctance to change from the old methods of economic evaluation and a feeling that the method is too complicated, costly and time consuming. Some managers feel that LCC as an economic evaluation method should not be the tool used as a basis for decisions. It should be borne in mind that a decision based on sound economic judgement is really important in minimising unnecessary future expenditure. LCC should be viewed as simply an alternative way of expressing values which are well established and acceptable as measures of economic viability e.g. present value and benefit: cost.

2.3.3 Data Limitation

The accuracy of LCC technique depends significantly on the availability of sound data for analysis. As shown in table 2.1, lack of reliable data was an important point discussed by most authors. In order to determine life cycle cost of a project with certainty, it is necessary to know the performance of its major elements. In this regard, it is important to know the likely life, replacement for each of these elements, and the extent to which such replacement would be carried out together with their costs. Such difficulties are commonly encountered in calculating the future life cycle costs. Suggestions were put up by BIRD, (1987), to set up a systematic data collection related to performance of projects. Such a structured data base was deemed essential.

2.3.4 Risk and Uncertainty

As indicated in table 2.1, risk and uncertainty were widely considered as the major factors which hindered LCC from gaining acceptance in the building industry. In order to reverse this concept, simple and practical techniques that directly address risk and uncertainty and give the decision makers comprehensive information on which to base their judgements should be developed. This requires incorporating risk management techniques in LCC, viz. sensitivity analysis to improve decision making.

2.4 CONCLUSION

Life cycle costing is viewed by various authors as a powerful decision making tool both in design and management. However, life cycle cost is not eagerly accepted by decision makers and manufacturers. Due to uncertainties and differing attitudes of decision makers and manufacturers, LCC is not widely used as decision making tool. There is the notion that the availability of historic data could assist in predicting future costs and that a relationship exists between capital and future costs. Such a relationship is possible if performance, value and life of the major components of a project are well established. Furthermore, risk and uncertainty associated with future costs used in LCC analysis leaves many people in doubt about the suitability of the method.

2.5 THIS STUDY

This study is an attempt to develop a methodology which will reduce the risk and uncertainty associated with the LCC technique in the construction industry by analysing the major components of a project. Emphasis will be put on trying to establish the performance of these components, the factors that influence their behaviour, and, if possible, determine their frequency between substantial maintenance works or renewal. A sensitivity analysis will be used to identify the impact on LCC of changes in a single or uncertain parameter used in the LCC such as, discount rate, running costs, capital costs and design life.

CHAPTER THREE

OVERVIEW OF LIFE CYCLE COST IN CURRENT USE

3.1 CONCEPTS AND APPROACHES

Life cycle costing sums discounted monetary costs of initial investment, salvage value, and maintenance costs over the study period. Life cycle cost philosophy has three main elements which are essential to effective decision-making. These are the components of life cycle approach:

(i) Life cycle cost planning (LCCP)
(ii) Life cycle cost analysis (LCCA)
(iii) Life cycle cost management (LCCM)

These are described in more detail in section 3.4. In short, LCCP is used during the design phase. LCCA and LCCM are used during the occupation phase when the project is in use.

Decisions in the construction industry have traditionally been made on a comparison of initial capital costs. It has been suggested that, since capital cost is the single most important cost, the lowest capital cost option will then be the lowest option. This implied that there were no real benefits to be gained from reducing running costs by increasing capital costs. So all the other costs were considered unimportant and could be ignored. However, FLANAGAN and NORMAN, (1983), believed that higher initial costs may significantly reduce operating costs and that capital and future running costs are intimately linked and should not be treated separately. STONE, (1967), came to the same conclusion. It is important that the LCC approach be adopted at the early design stage so as to be effective in the management of existing projects.

3.2 LIFE CYCLE IMPLEMENTATION

LCC represents a particular application of classical investment appraisal techniques. The techniques used incorporate initial investment costs, such as design, and construction costs; replacement costs; operation, maintenance and repair costs; salvage values and disposal costs; and other significant non quantifiable aspects (in monetary terms) of the project. Cash flows are discounted to a time base and the total value of the discounted sums is used as a measure of economic performance. As these techniques take into account cash flows over time the whole life of the project and not only initial costs, they are at times referred to as Life-Cycle Methods.

3.2.1 Steps in Economic Evaluation

Step 1. Establish the objective
Step 2. Choose a method of economic analysis
Step 3. Formulate assumptions for analysis
Step 4. Identify the costs and the life cycle
Step 5. Compare costs and rank the alternatives
Step 6. Sensitivity analysis of data and assumptions
Step 7. Investigate capital cost constraints.

Step 1. Establish the objective

A clear statement of the required objective to be achieved by the economic evaluation is important in selecting the best method of evaluation and structuring the problem for solution. Usually the economic objective is; to determine which design of a new project will have the lowest initial and operating costs while fulfilling its functional requirements or; to determine what priority should be given to projects competing for limited funds.

Step 2. Choose a method of economic analysis

Having established the objective, the next step is to determine the range of feasible methods for achieving that objective. This requires taking into account all realistic possibilities to assist the decision-maker in making resource allocation decisions. Sometimes, administrative constraints on time, resources and available data may tend to restrict choice. Take for example, the situation in which two alternatives have been presented:

Option 1: Timber bridge - Project A
Option 2: Concrete bridge - Project B

Project A is favoured because of its lower life cycle cost option. However, a third option, bridge C is not considered because its construction cost estimates are thought to be outside capital budget constraints. Further investigation indicates that bridge C offers considerable savings in running costs and in fact turns out to be the lowest life cycle cost option. Such an option should be brought to the notice of the decision-maker. Even if he still opts for project A he should do so in the knowledge that it is not the most-cost effective solution.

Step 3. Formulate assumptions

LCC deals with future expenditure and thus involves elements of uncertainty. Getting a factual picture of what is to be constructed may be a problem, so this may require making certain assumptions in order to proceed with the analysis. For example, it may be necessary to forecast escalation of labour, material and energy. Accurate identification of such data is necessary, and where factual data are available then estimates should be based on modifications of this.

Step 4. Identify the costs and the life cycle

For each possible choice of project, determine the life cycle of the project and of the individual components of that project, plus all costs recurring during the entire project life cycle. This is one of the most difficult areas to do accurately. However, in this study efforts have been taken to use reliable data and also to show how best this can be achieved. Lives of various elements of certain projects can be predicted from observed data on failure. Project life is also a major variable. It can be extended by periodic maintenance and replacement or may be foreshortened by changing economic, social or legal conditions as well as advances in technology. The life cycle of a project is often based on either its economic or functional life.

Step 5. Compare costs and rank the alternatives

This is the most important step of a LCC approach. The techniques that are used at the moment for ranking alternatives are the following:

1. Net present value (NPV)
2. Internal rate of return (IRR)
3. Annual equivalent value (AEV)

These are described in more detail in section 3.3. All these methods are fully consistent with an LCC approach as they take into account all relevant values and discount them to a common time basis.

Step 6. Sensitivity analysis

If step 5 does not clearly indicate the obviously outstanding project, it is advisable to test the sensitivity of the analysis to certain dominant cost factors and assumptions in order to give the decision-maker a complete picture of the various projects' viabilities.

Sensitivity analysis facilitates evaluation of a project when there is uncertainty about the data and assumptions. There may be, for example, uncertainty about the discount rate, the life of the project or its future repair costs. The uncertainties may raise doubts about the project's potential cost effectiveness. Sensitivity analysis is carried out by repeating an evaluation using different input values. Detailed approach of this technique will be dealt with in chapters 5 and 6.

Step 7. Investigate capital cost constraints

LCC procedures should include a step in which the initial costs are examined to ensure that they do not exceed the total funding available. If this constraint is exceeded, trade-offs should be made until the optimum combination of lowest life cycle cost within available funding has been attained.

3.2.2 Take Into Account Unquantifiable Effects

If all the major aspects of a project are not adequately incorporated in the numerical evaluations, the measure of economic performance taken alone may be misleading. It is important to consider (in $ terms) non quantifiable as well as quantified aspects, in the evaluation procedure in order to make a decision. Some of the intangible aspects may be either environmental issues or social factors. For example, in a road project, aspects such as noise and dirt due vehicles using the road should be considered in the analysis. Secondly, construction of a road may significantly obstruct the environment as well the existing social patterns in the region.

3.3 DISCOUNTING CASH FLOWS TO PRESENT VALUE

3.3.1 General

Given that money at a future date is not equivalent to the same sum of money now, a central problem in life cycle costing is to reduce to common base cash flow expenditures and receipts that arise at different points in time. It is very important to identify a meaningful exchange rate between money now and money at a future date. This exchange rate is referred to as the time value of money over a study period, a process called discounting is used to put cash flows on a time equivalent basis, in other words to their "present value".

3.3.2 Discount Rate

Discount rates might appear, at first sight, to be synonymous with interest rates. However, this is not the case. An interest rate is made up of two components, firstly the time value of money and secondly the effects of inflation. A discount rate should not include inflation at all.

The discount rate to be used in the evaluation of the present value will depend on the circumstances and the objectives of the client. The techniques used in discounting are those indicated in section 3.2.1 step 5.

3.3.3 Net Present Value

The net present value (NPV) of the future costs, over the period of analysis agreed, are all discounted from the date at which they will occur back to the present and then summed to produce the net present value of the life cycle cost of the project. The value obtained is used in ranking projects with identical lives from alternative options. The options may be alternative construction projects, say bridges, elements within bridges, or components or alternatives for the same project.

In this approach, the best option is that with the lowest NPV which is equivalent to the lowest cost. The NPV method commonly applies to situations where there are widely varying sums of money paid out or received over a period of time. The general formula used in calculating the present value (PV) is as follows:

$$PV = S[1/(1+r)N],$$

where: S = Future sum of money equivalent to PV at the end of N periods of time at r interest or discount rate.
r = Interest or discount rate.
N = Periods of time.

3.3.4 Equivalent Uniform Annual Cost

This annual cost method of comparison takes into account both the capital and the recurrent investment made over the full period of assessment. All expenses incurred at any one time during the assessment are charged on an annual basis, taking into account the time value of money. In converting to annual cost for the purpose of comparison, all payments and receipts, however diverse they may be, are converted to equivalent uniform annual costs or equivalent annual cost (EAC). The best option is that with the lowest EAC. The general formula for use in calculating uniform annuity cost is as follows:

$$EAC - PV.\frac{(1 + r)^{N}.r}{\left[(1 + r)^{N} - 1\right)},$$

where PV = Present value of costs.
N = Period of time in years
R = Discount rate or interest.

EAC as a method of comparison is more readily understood than present value and it is used to compare or assess schemes involving more or less regular annual cost. In particular this is used for ranking projects with different lives. Where annual costs are irregular, the method necessitates their conversion into regular annual costs by first converting to present worth.

3.3.5 Internal Rate of Return (IRR)

This technique takes the costs and benefits of competing options and identifies the option which gives the greatest rate of return. This is done by calculating the discount rate which gives the NPV of zero to the sum of the present values of total benefits and total costs. The disadvantage with this technique is that it is more difficult to calculate than other investment appraisal techniques given above. The reason is simply that the IRR is an iterative solution which, on its own, contains logical errors in its methodology. This technique will not be considered as one of the means of investment appraisal methods for life cycle costing.

3.4 COMPONENTS OF LIFE CYCLE COST

3.4.1 General

In section 3.3 different methods of project economic evaluation have been viewed. These methods, viz PV, EAC and IRR were used to calculate the whole life costs of projects by considering both their initial and future costs. In dealing with the future costs of a project, a life cycle cost system is applied. This system consists of three main components known as:

(i) Life cycle cost planning (LCCP)
(ii) Life cycle cost analysis (LCCA)
(iii) Life cycle cost management (LCCM).

3.4.2 Life Cycle Cost Planning

LCCP is simply a component of the LCC approach which deals with the planning of future costs. It works on the same principle as capital cost planning where in that estimates are based on target costs. The designer sets an estimated cost target for each of the chosen categories in the LCCP and the cost target provides a constraint and a measure against which design solutions can be compared. It has the ability to handle both initial and continuing costs, reducing them to a common denominator which is then used as part of the decision process. If a decision has no continuing cost consequences, then LCCP should not be carried out.

3.4.3 Life Cycle Cost Analysis

Life cycle cost analysis is a collection of data on the running cost and performance of an existing project such as a building or a bridge. The main use of LCCA is as a management tool intended to identify the actual costs incurred in operating projects or any durable assets. LCCA serves as a means of generating an historic data base which can be used to highlight areas in which cost savings might be achieved in the design, operation, and in the choice of projects or individual project components. LCCA deals only with historical costs and does not involve discounting. The problem associated with LCCP is lack of access to running cost data and efficient LCCA overcomes this. Even where access is given, lack of any standard format under which such data should be collected does not allow full extraction of all the relevant cost elements for LCCA.

3.4.4 Life Cycle Cost Management

Life cycle cost management follows on from LCCA. It is the means by which running costs observed during LCCA are reduced, either by a change in operating practice, or by changing the relevant system. LCCM establishes where performance differs from LCCP projections and the actions to be taken. It makes a recommendation on how a project may be operated and utilised more efficiently. Furthermore, it provides information on asset lives and reliability factors for accounting purposes. LCCM serves as one of the vital areas for the application of life cycle cost techniques.

3.5 SUMMARY AND CONCLUSION

1. This chapter has given a view of concepts and approaches of life cycle costing.

2. The life cycle concept by itself does not make the decision. It serves only as a managerial tool for decision-makers. However convincing and precise the results of the analysis may be, professional skill and judgement still presides.

3. Accuracy of LCC technique depends on the availability of reliable data for analysis.

4. If LCC is to provide the decision-maker with sufficient information, it is necessary to perform a sensitivity analysis to allow greater understanding of the effects and influences of the major elements of the most desirable option.

CHAPTER 4

METHOD OF COST ANALYSIS

4.1 GENERAL

The total life cycle cost (TLCC) technique has been pointed out in the previous chapters as the best method for carrying out economic evaluation of projects when taking their future costs into account. This chapter is aimed at relating the method of analysis used in this project with the concept of TLCC technique. A spreadsheet programme has been used. All relevant data required in the analyses is explained in chapters 5 and 6.

4.2 OVERVIEW OF VP-PLANNER PACKAGE

VP-Planner includes both a worksheet and two types of database: a relational database conforming to databases II and III file standards, and a separate multidimensional database. In this study only the VP-Planner worksheet is used to carry out the analysis.

4.2.1 Worksheets

Worksheets are computer programs; also known as electronic spreadsheets. This is organised into rows (which run across the screen and are numbered) and columns (which run up and down the screen and are labelled alphabetically). Where a row meets a column, the intersection is called a cell. Cells are the basic working unit of the worksheet. Cells are used to hold entries to the worksheet and are identified by their row and column number (e.g. E4, H20, etc.).

Entries to the worksheet

VP-Planner facilitates execution of three entries to a cell, viz. label, number and formulas. Each of these entries performs a different function in the programme.

(a) Labels

Labels or text entries are used to describe and document the contents of the various areas set upon the worksheet. Labels can include column or row headings, running text, or graphic markers to divide column sections of a large worksheet from one another. Furthermore, labels are used to define macros - sequences of commands that can be executed with a single keystroke.

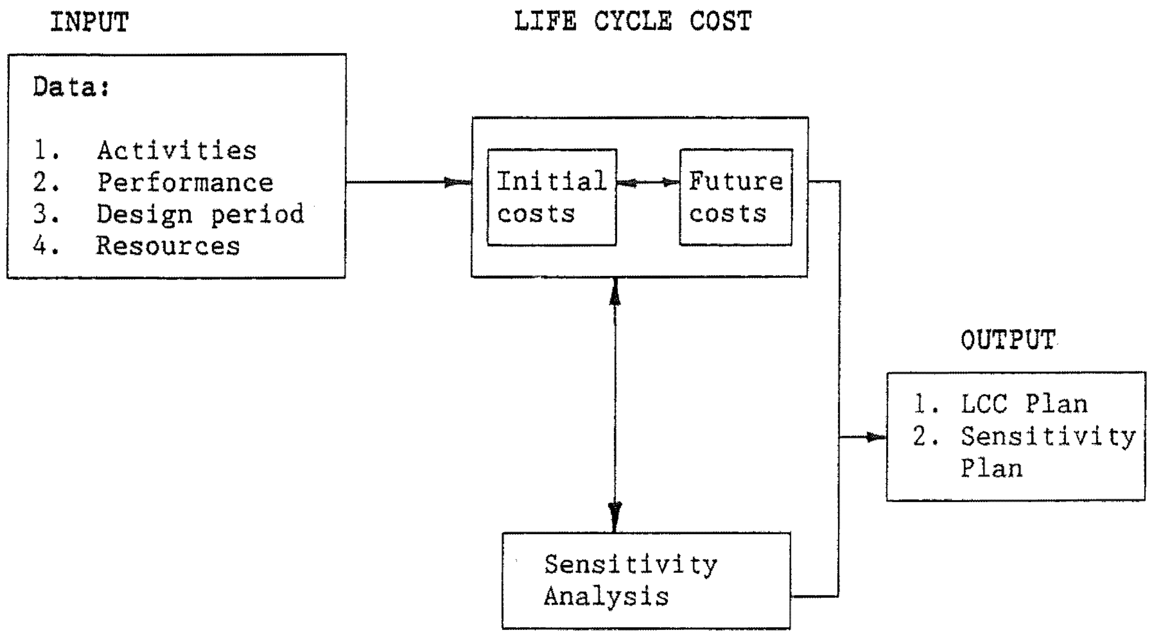
(b) Numbers

Numbers or values are used as raw materials which the VP-Planner worksheet processes. Values in VP-Planner are taken in the same form, but can be displayed in several formats. The numerical formats consist of fixed, scientific, currency, comma, percentage, date and general. For example, in general format, numbers are displayed just as you type them, unless they are too large to fill the column. In this case they are displayed in scientific notation.

(c) Formulas

Formulas are used to link other cells together to create powerful models that respond to changes made in a parameter. Formulas are generally made up of relative references or cell addresses. Thus you can create input cells, for entering numbers to be used within a set of formulas in a model. Formulas can be set up in order to retrieve the results of other formulas before running their calculations. As a result, alterations to the contents of a single cell can affect the results displayed throughout an entire worksheet. This is the main reason why this package was specifically chosen for carrying the analysis in this study. It can be used to perform a sensitivity analysis, a univariate approach that identifies the impact of a change in a single parameter value.

4.3 GENERAL OUTLINE OF METHOD



The output is used to select the most cost effective project from a given set of alternative options. In other words, the output serves as a tool for decision-makers.

4.4 OUTLINE OF INPUT

Step 1. Identify the major components for the particular project.

Step 2. Set up a cost database.

The cost data include:

(i) Material costs
(ii) Labour rates
(iii) Plant and Equipment hiring rates
(iv) Overheads

WKs.file: A file is created, i.e WKs.file = Worksheet file, to facilitate subsequent analyses.

Db.SPs: This indicates the spreadsheet created in a file to store the data. These abbreviations are used in the flow chart diagram.

An example of the spreadsheet input cost data file similar to that used in the road project analysis is shown below.

Table 4.1: Cost Data Estimates of Various Components for the Road Project

Item	Description	Unit	Unit Costs ($/unit)
2	Bulldozer 100 hp	hr	100
3	Diesel fuel	hr	0.60
4	Skilled labour	hr	22

Step 3. Establish the activity time estimates together with their labour costs.

Data required include the following:

(i) Equipment
(ii) Manpower
(iii) Productivities for equipment and labour
(iv) Quantity of work for each activity
(v) Labour rates.

The example below shows the spreadsheet input data setup to determine the activity time estimates and their labour costs.

Table 4.2: Activity Time Estimates With Their Labour Costs for the Road Project

1	2	3	4	5	6	7	8
Description	Input	Input No.	Unit	Production (Qty/unit)	Duration (hrs)	Labour $/Qty	Total $/Qty
I N P U T				O U T P U T			
EARTHWORK:							
Cut to fill	Dozer	1	hr	33	394		
	Roller	1	hr	122	394		
QUANTITY:	Foreman	1	hr		394	0.67	
	Operator	2	hr		394	0.67	
13000 m^3	Worker	2	hr		394	1.09	3.09

Step 4. Establish the equipment cost estimates including operators for carrying out construction works.

The data necessary for activity unit rates include:

(i) Fuel and hiring cost data from step 2
(ii) Equipment time estimates from step 3
(iii) Productivities for equipment

The example below shows one of the setups the spreadsheet input data used in the analysis to determine the equipment unit costs.

Table 4.3: Equipment Cost Estimates Including Operator for the Individual Activities of a Road Project

1	2	3	4	5	6	7	8	9	10	11
			E Q U I P M E N T							
Description	Unit	Method	Prod	Fuel Used	Usage Time	Req'd Time	Fuel Cost	Hiring Rates	Unit Cost	Sum
I N P U T									OUTPUT	
EARTHWORK										
2. Cut and fill		C-I								
1 bulldozer	m^3		33	19	394	394	11	100	3.37	
1 roller	m^3		122	21	107	394	12	50	1.62	4.99

Step 5. Establish the construction costs of the project or alternative project options.

The data necessary for this include the following:

(i) Activities/operations
(ii) Quantities of works
(iii) Unit rates

Step 6. Establish the maintenance costs.

Maintenance work consists of:

(i) Operations
(ii) Operations frequencies
(iii) Design life
(iv) The percentage of work carried out on a particular activity
(v) Discount rate
(vi) Costs

Step 7. Establish the road user costs.

The data necessary consist of:

(i) Capital costs
(ii) Maintenance costs
(iii) Vehicle operating costs

Note: This step applies only to road projects it is not executed for other projects such as bridges. A detailed outline of working out user costs is dealt with in appendices B and C.

Step 8. Perform a sensitivity analysis of TLCC to changes in certain parameters.

Data necessary include the the following:

(i) Construction costs
(ii) Maintenance costs
(iii) Road user costs (if required)
(iv) Risky or uncertain parameters

4.5 OUTLINE OF THE METHOD

4.5.1 General

The method involves determining the life cycle cost of a project or alternative project options by calculating their initial and future costs for a given design life. The initial and future costs are added together to get the LCC of a project for a given design life. In order to minimise the risk and uncertainty inherent in LCC, sensitivity analysis is carried out by varying certain parameters considered to have an effect on the LCC.

4.5.2 Cost Database

A cost database is set up from a collection of all items necessary together with their unit prices to form a worksheet. This data is later used in working out the unit costs of particular activities.

4.5.3 Activity Time Estimates and Their Labour Costs

(a) Activity time

The project time estimate is arrived by identifying all the activities or operations necessary to perform the construction or maintenance works and setting up a spreadsheet. Secondly, the manpower and equipment productivities necessary to perform an activity are also entered together with their unit numbers. Finally, using this input data, time to execute the various activities is determined depending on the construction technique used. For example, the time taken to carry out Activity 3 table 2 for a Road Project (see Appendix B), is the maximum of time to excavate and time to compact since these two activities are interdependent. Therefore, the duration of the activity depends on the slowest operation. The time allocated for each individual equipment and manpower necessary to execute the operation is therefore equal to the maximum time. This is indicated in step 2 above.

The activity time is calculated as follows:

$$\text{Activity time} = \frac{\text{Quantity of Work}}{\text{Output}},$$

where

Output = Productivity of equipment/labour force x their units of input.

(b) Labour unit cost

The labour unit costs of individual skilled and unskilled labourers are determined and then summed up to get the labour unit cost for that activity. Derivation of Column 7 in table 2 (step 3) above is shown below.

$$\text{Column 7} = \frac{\text{Value from Column 6 x Labour Rate from Cost Data Table 1}}{\text{Quantity of Work for the Activity}}$$

4.5.4 Equipment Cost Estimates

The costs of using the equipment to perform a particular activity are worked out by using their required and usage time as well their fuel consumption. This is possible, if the productivity and horsepower of the equipment is known. The fuel cost is calculated by using the fuel consumed multiplied by the usage time and fuel cost rate. Unit cost is arrived at by summing up the costs for fuel and hire necessary to complete an operation/activity then divide this value with the amount of work to be performed.

4.5.5 Construction and Maintenance Costs

Having determined the costs for labour, materials and equipment, these costs are summed up to get the unit rates necessary to execute an activity. Finally, the costs of the individual activities of a project are summed up to get either its construction or maintenance costs. However, the maintenance costs of a project are worked out for the year in which they occur, and these values are discounted back to the base year of the analysis. The discounted values are summed up to get the maintenance cost of a project for a given design life.

The total life cycle cost (TLCC) of a project is arrived at by summing the values of construction and maintenance costs.

Total life cycle cost is arrived at as follows:

TLCC = Initial costs + Future costs discounted to present time

where

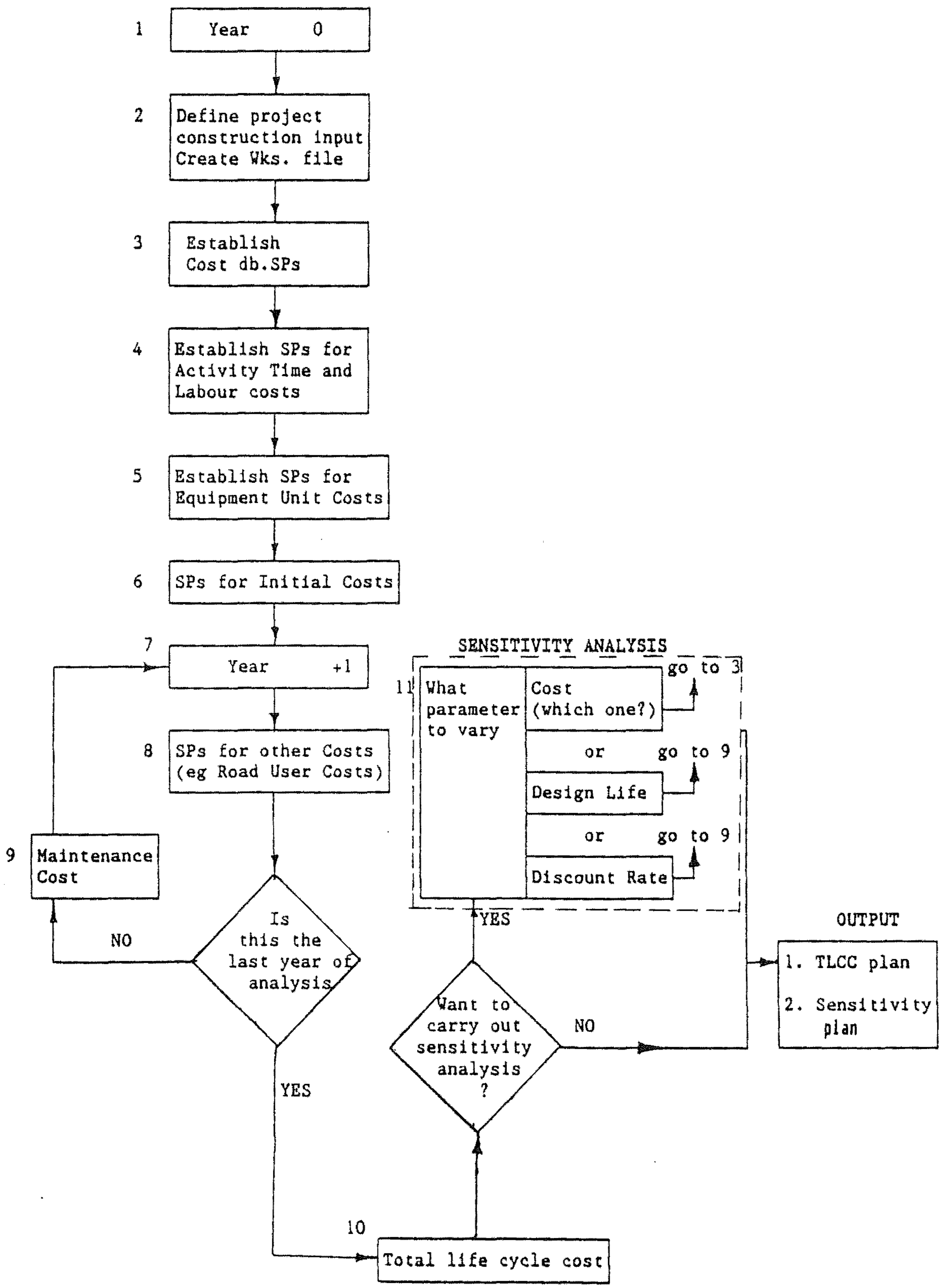
Initial costs = Capital/Construction costs

Future costs = Maintenance costs

4.6 SENSITIVITY ANALYSIS OF TLCC

Sensitivity of a TLCC is carried out to test its impact to a change in a single risky or uncertain parameter used in the analysis. This parameter is varied and its results are put in a tabulated form to assess the impact they have on the TLCC of a project or alternative options of a project.

Fig. 4.4: Outline of the Flow Chart of the Programme



4.7 SUMMARY

This chapter has presented how TLCC or sensitivity of TLCC to changes in a single parameter of a project or alternative project options can be achieved with the use of a VP-Planner package. A step by step procedure of how this programme works has also been presented. The detailed results are given in the appendices.

CHAPTER 5

BRIDGE PROJECT

5.1 GENERAL

It has been a common practice in the past to build bridges and then pay them little attention. This approach was considered acceptable as bridges were thought to last for a long time without repair. Some of the reasons for this were that the old bridges were constructed from durable materials such as stones and hard timber which could withstand severe environmental conditions.

As these materials became scarce and expensive to obtain and work new materials, such as steel, concrete, and soft timber, were introduced as a substitute for the old ones. Furthermore, advancement in technology, particularly more heavy vehicles, necessitated the introduction of stronger structural material with high loading carrying capacity. Bridges are required to have a long life and to be serviceable over a long period of time. Costs do not cease with the construction, but continue throughout the life of the bridge in the form of maintenance and other running costs. Thus it is important to devise economic evaluation techniques, which take into account both initial and future costs in their analyses.

This study addresses itself to such a situation by using life cycle costing technique to overcome this problem. Life cycle cost (LCC) technique has the ability to deal both with the future as well as the initial costs. Due to uncertainty inherent in the future costs which are part of the LCC, risk management techniques are incorporated in it to reduce the risk and uncertainty associated with it.

5.2 SCOPE OF STUDY

A single lane vehicular bridge of length 24 m with different superstructure types was considered as listed below and illustrated in Figs. 5.5, 5.6 and 5.7. The bridge types investigated are:

(i) Precast, prestressed concrete U-beam bridge
(ii) Precast, prestressed concrete I-beam bridge
(iii) Composite built steel beam bridge
(iv) Composite timber beam bridge.

A standard design was chosen for each of these bridge types. The costs of the bridge types were estimated basically by considering the major components of their superstructures and substructures, see Appendix A. The same substructure was used throughout for each of the four bridge types. Cost estimates used in this study were arrived at with the assistance of The Works Corporation (New Zealand). This was possible because this Corporation has vast experience in bridge design, construction and maintenance.

The approach detailed in step 4, section 3.2.1, which deals with cost identification and life cycle of projects or elements of the projects is investigated in the following sections of this chapter. As a basis for study a value of 10% discount rate is adopted as this is a commonly used value for public sector discounting purposes in New Zealand.

Simple sensitivity analyses of total life cycle costs are carried out by varying the discount rate, design life, costs and project's major component.

5.3 ALLOCATION OF COSTS

5.3.1 General

Costs of construction work depend on a number of varied factors. For example the type of job, the location of the job site and the construction period significantly affect the overall cost of the job. The costs that are of paramount importance for this study are capital and future costs. These costs constitute life cycle costing approach, a technique adopted in this study for project investment appraisal.

Capital costs include site acquisition, design and construction costs, whereas future costs comprise of maintenance and operating costs. Capital costs in this report are taken as equal to costs of construction since the the acquisition and design costs in this study are assumed as being constant and their omission will have little effect on the analysis. In order to analyse the initial and future costs methodically, it is essential to identify the basic elements that constitute the bulk of these costs.

The costs of work are classified as follows:-

1. Material costs
2. Labour costs
3. Plant & equipment costs
4. Overhead costs
5. Profit

5.3.2 Material Costs

Generally, the material costs vary according to quality, quantity and site location. Site location is perhaps the most vital factor governing the final price of materials. The project investigated in this report is not related to any particular site, so the cost of delivery of materials to the site is incorporated under overhead costs. As to the cost of materials, the unit market rates in New Zealand construction handbook (RAWLINSONS 1989) are used.

5.3.3 Labour Costs

Labour costs may be examined from two aspects:

1. Labour rates: the hourly rates of employing workmen, based on total costs divided by the total number of hours worked.

2. Productivity: the rates of production of workmen employed; the amount of work done in a specific period of time.

5.3.3.1 Labour rates

Labour rates incorporate both the direct labour costs as well as the indirect labour costs. Workers in this investigation are classified into two groups, viz. skilled labourers and unskilled labourers. Unskilled labourers are used for carrying work which does not require expertise.
Skilled labourers include:-

1. Carpenters
2. Foremen of craftsmen
3. Mechanics
4. Plant
5. Operators
6. Truck drivers
7. Labour foremen.

5.3.3.2 Productivity

Productivity is defined here as the rate of production by workmen employed or the amount of work done in the specific periods paid time. This is one of the major factors in all construction costs.

5.3.4 Plant and Equipment Costs

Plant and equipment costs fall into two basic categories:

(i) Owning costs: the costs of owning plant and equipment,

(ii) Operating costs: the costs of using the plant and equipment over and above the owning costs.

5.3.4.1 Owning costs

These costs are identified as:

(i) Depreciation (loss in value from any cause)

(ii) Maintenance (major repairs and replacement of parts)

(iii) Investment includes;
- interest on investment,
- investment and taxes on plant & equipment,
- storage costs.

5.3.4.2 Operating costs

These costs are identified as:

(i) Fuel (including lubricants and additives)

(ii) Running repairs (including minor repairs and replacement of small parts)

(iii) Transportation (including transporting to and from site, setting up and dismantling)

(iv) Operator (including wages and fringe benefits).

The methods used to calculate these costs may be referred to in a standard text on construction costs (KEITH 1974). Plant and equipment costs used in this study are based on hourly rental rates. Basically, the rental rates cover owning costs, transportation costs and operator's cost.

5.3.5 Overhead Costs

These are construction costs of any kind that cannot be attributed to any specific item of work. Overhead costs fall into two categories, viz. (a) site operating costs and (b) operating overhead costs.

(a) Site operating costs

These costs can be estimated in the same way as other costs of the work, because they include material costs, labour costs, plant and equipment costs. The site overhead cost is estimated as a percentage of the total cost of the project. The site overhead cost of 10% has been adopted here in the analysis for the bridge project.

(b) Operating overhead costs

These are costs that cannot be attributed to any particular job. These are often known as, head office overheads. Such costs are often incurred by a contractor regardless to whether or not he is actually doing construction work.

Operating overhead costs may include:-

1. Management and staff, including:
    (a) salaries, fringe benefits and expenses,
    (b) transportation for site supervision,
    (c) other expenses attributed to staff and not chargeable to a specific job.
2. Business offices, including:
    (a) rent,
    (b) office equipment and supply,
    (c) other such,expenses attributable to operation of the company but not attributable to any specific construction job.
3. Communication, including:
    (a) telephone, telex, fax and postage etc.,
    (b) promotion and advertising.

No specific percentage rate was adopted for the operating overhead costs as this was not considered to be important for this study.

5.4 MAINTENANCE AND REHABILITATION

5.4.1 General

In analysing the future costs it is particularly important to identify the fundamental elements that constitute the future costs of a construction work. Future costs of, say a bridge construction, fall into two categories, viz. 1. maintenance and 2. rehabilitation.

5.4.2 Bridge Maintenance

The most common problems encountered in bridge maintenance involve routine work. Work carried out by most maintenance crews on bridges involves:-

1. removal of dirt and debris,
2. cleaning and painting,
3. snow and ice removal,
4. patching or overlaying the deck.

5.4.2.1 Removal of dirt and debris

Corrosion of steel reinforcement is one of the major causes of bridge deterioration. The corrosion process requires the presence of water to remain active. By removing the debris from bridge deck, around bearing areas, at expansion joints, in drainage devices and on bridge pier caps is very important for retarding corrosion by reducing the capacity for water storage.

5.4.2.2 Cleaning and painting

Cleaning and painting of bridge members is also very important. By adopting a regular program for cleaning and spot painting of localized areas of rapid paint failure, such as beam ends under floor drains, prevents corrosion and prolongs the life of the entire paint system.

5.4.2.3 Deck Overlaying

Chemical action on the concrete, when used for snow and ice removal, or the abrasive action of traffic make deck overlays an important consideration in bridge maintenance. The overlays improve the riding surface or protect the concrete deck.

5.4.2.4 Repair of Traffic or Collision Damage

This is one of the important areas of bridge maintenance. Truss bridges are particularly prone to traffic damage, since most are narrow and all the main load carrying members are often above the road surface. The wheel guards or guardrails are also susceptible to traffic damage.

5.4.3 Bridge Rehabilitation (Refurbishment)

The difference between bridge repair or maintenance and bridge rehabilitation is rather ill defined. However, the distinction lies in the extent of repairs required to bring the bridge up to an adequate condition. Rehabilitation is usually intended to extend the service life of an existing bridge until such time when money, time, and manpower are available to replace the structure.

Rehabilitation includes:

1. Deck replacement and minor repairs,
2. Correction of settlement problems,
3. Strengthening or replacing critical members, viz. bearings,
4. Widening or correcting alignments,
5. Improving drainage,
6. Overlaying the deck,
7. Painting.

5.4.3.1 Deck replacement

Replacement of the deck, or of the deteriorated portions of the deck, is the most common bridge rehabilitation. Deterioration in bridge decks is often caused by chloride penetrating concrete and corrosion of the reinforcement due to de-icing chemicals placed on bridge decks.

Bridge decks with less than 0.6 kg of chloride per cubic metre at the rebar level are protected by overlaying with a water proofing membrane or low slump concrete. Bridge decks with greater than 1.6 kg of chloride per cubic metre at the rebar level, require removal of the contaminated concrete to below the reinforcing bars, sandblasting of the rebars, coating the rebars with an epoxy protection material, and pouring new concrete. If more than 40% of the the surface area of the bridge deck is contaminated, a complete replacement of bridge deck is usually carried out, (KENNETH 1981).

5.4.3.2 Girder replacement or strengthening

(a) Concrete members

Concrete member refurbishment includes external steel reinforcement being attached to the member by means of bolts extending through the member. Furthermore, if the floor or deck system only is inadequate, supplemental steel or precast concrete members are used to enhance the overall capacity of the bridge.

(b) Steel members

These are often strengthened by adding cover plates or web plates depending on the critical stress mode. Steel girder bridges are usually strengthened by composite action. This is carried out by providing a shear connection between a concrete deck and the steel beam. During this process the studs are welded to the beams to provide the necessary shear transfer for composite action. Other approaches for accomplishing such shear connections are drilling holes through the deck for attaching studs and epoxy injection between beam and deck. Existing steel bridges are usually strengthened by splicing together simple steel beams for continuity.

(c) Timber bridges

Rehabilitation of timber bridges is easier when compared with steel and concrete bridges. One of the methods used in accomplishing the repair is to simply to add supplemental members to timber or steel to reduce the load on each member.

5.4.3.3 Dead load reduction

In order to increase the load-carrying capacity of a bridge, it is usually necessary to reduce its dead load. Take for example, older bridges where the asphalt overlays have accumulated up to a point were the dead load from the overlay is significant. This can be overcome by merely removing the excess overlay material. In other circumstances the entire deck may be removed and replaced by a lighter weight decking material.

The three common materials used for new decks on older bridges are:

1. The open grid steel flooring,
2. Corrugated metal plates with asphalt
3. Laminated timber decking.

5.4.3.4 Geometry

Improvement of bridge geometry includes:

1. Vertical clearances,
2. Widening of the roadway,
3. Horizontal or vertical alignment.

With the type of bridges under consideration in this study, the sort of geometry improvement likely to be carried out would be roadway widening. Roadway widening on most bridges involves removal of sidewalks and curbing, extending piers and abutments, and adding new stringers and a new deck to meet the demand due to increased traffic.

5.4.3.5 Safety and serviceability

This involves replacement of inadequate bridge railings and alteration of bridge railing or guard railing ends. Adjustment of roadway alignment may have a significant impact on the safety record of a bridge. Repair of approach-slab settlement at the end of bridge can considerably improve the serviceability of a roadway. Deck repairs of pot holes and slippery areas can improve the safety and riding comfort of a bridge.

5.4.4 <u>Maintenance Costs</u>

In this study most of the maintenance works on the four types of bridges considered are based on similar work previously performed on bridges in New Zealand. Where cost estimates on previous maintenance works were not available, maintenance costs were derived by estimating the likely amount of maintenance work required every year on these type of bridges. In order to ascertain the validity of the estimated costs, these figures were compared with the realistic costs spent on maintaining bridges by the New Zealand Works Corporation.

5.4.5 Rehabilitation/Refurbishment Costs

It was considered important to have a rough idea of the design life of the major structural components of the bridge types, in order to establish the amount of work required for repair at a given time. Knowing the rate of deterioration of the the main structural components, say the bridge deck for example, and the factors that lead to it, it was easier to arrive at the estimated amount of work involved for refurbishment and the related costs. Tables A.10, A.11 and A.12 show detailed analysis of rehabilitation costs, see Appendix A.

5.5 BRIDGE DESIGN LIFE

5.5.1 General

In order to facilitate accurate prediction of future costs of any construction project, it is considered important to have some knowledge of the life of its major components. This in itself serves as a guideline in establishing the service life or study period of the project, as well as determining when repairs are required due to the deterioration of major components.

Deterioration of structures start at varying rates, even during the construction period, and thereafter due to exposure to the environment, whether from temperature, moisture, chemical attack, freeze/thaw cycling, ultraviolet light exposure or stress/strain cycling. The problem is to establish the expected life of the structure.

5.5.2 Deterioration of Structures

In order to arrive at an acceptable design life of structure, it is necessary to know the behaviour of its individual components in the environment to which it is exposed. The environment in which the structure is situated has a significant effect on its life. A clear knowledge of the environment at the design stage is essential, particularly when aggressive substances are present. If such substances are not taken into consideration, rapid deterioration can take place. All materials in use degrade with time, for example, timber rots, steel corrodes, joint seals debond and leak, and paints flake and discolour.

In this report attempts are made to establish the factors that cause degradation of structural material, and how they influence its service life. The main components of the bridge investigated are steel, timber and concrete. Once the rate of deterioration of the individual components of a structure are established, it is then possible to determine its likely service life.

5.5.3 Corrosion of Reinforcement

The primary environmental factors responsible for steel corrosion are carbon dioxide (CO_2) from the air or chloride deposited on the surface of the structure, together with moisture, oxygen and temperature (BROWNE 1989).

For corrosion and damage to occur these three conditions have to exist;

1. Chlorides or carbonation (Steel depassivisation),
2. Oxygen or moisture (Fuel),
3. Chlorides water (Low concrete resistivity).

Table 5.1 summarises commonly identified sources of corrosion attack due to chlorides and the type of structures and components affected.

Table 5.1: Structures and Components at Risk

Source	Structural Element at Risk	Components/Specific Structures
Added to concrete at mixing:		
1. Calcium chloride (as an accelerator)	Precast units in-situ (winter concreting)	Cladding, columns, beams
2. Salt contamination (from water, aggregates)	All elements	All elements
Seawater exposure	Over water structures Foreshore structures/ buildings Industrial plant Tunnels in seawater/ bearing ground	Bridges, jetties, wharves, dry docks. Collection of airborne salts, including chimneys, storage tank bases, seafront building facades. Seawater cooling (e.g. intakes, flumes, pipe supports), areas exposed to seawater washdown or seawater fire fighting systems. Segments/joints.
De-icing salts	Bridges	With/without deck membranes, deck joints, piers

5.5.4 Time to Damage

The time to damage (t) is mainly a two stage process (Fig. 5.1), (BROWNE 1989), which is defined as:

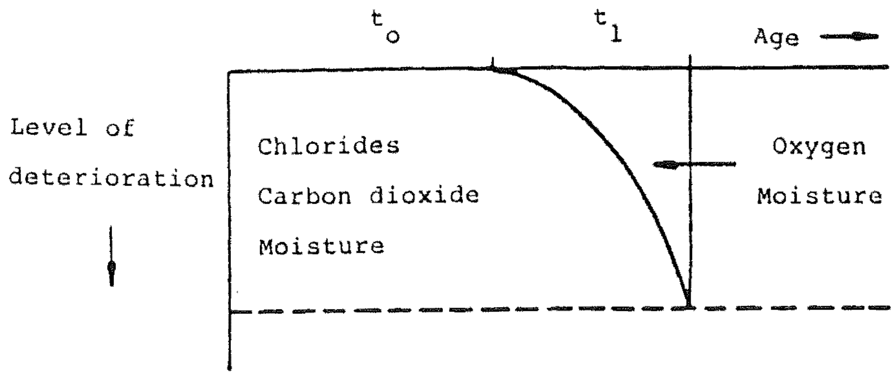
$$t = t_o + t_1 \qquad (1)$$

where t_o = the time for the environment to penetrate into the concrete to a level where attack starts,

t_1 = the time taken for deterioration to became significant.

t_o is a finite stage determined when the chloride threshold had been reached at the steel or the carbonation front has penetrated to steel depth. t_1 is a subjective stage, which varies from a few months to many years depending on the rate of corrosion that can be maintained and the amount of damage. The extent of damage of the structure due to corrosion will depend on the function of the structure and the location of the damage. For example spalls dropping from the cladding of bridge soffits may be hazardous to traffic beneath. Cracks and delaminations to columns, beams and slabs may result in a reduction in strength of the member. Furthermore, damage may result in loss of appearance to the structure rendering it aesthetically unacceptable.

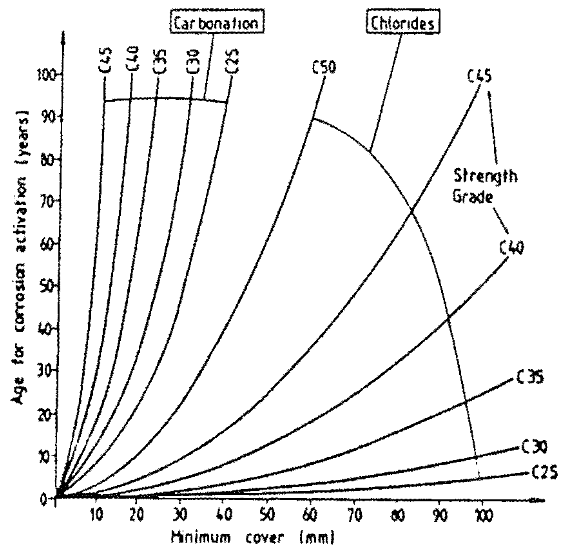
Fig. 5.1: The Time to Damage Concept (1)



5.5.4.1 Calculation of penetration rate

It is a well established fact that reinforcing bars in concrete structures, such as concrete deck slabs, beams and abutments, are damaged due to penetration of carbonation and chlorides to the rebar levels causing corrosion to take place (BROWNE 1989). Figure 5.2 (given below) illustrates the penetration rate of these two factors depending on the quality of concrete and the cover to the rebars. In this study Figure 5.2 will be used to estimate the design life of structures. This life estimate is conservative, as only (t_0) has been estimated since this value is considerably greater than (t_0) as indicated in section 5.5.4, equation 1. The design life estimate from Fig. 5.2 applies particularly to reinforced concrete structures.

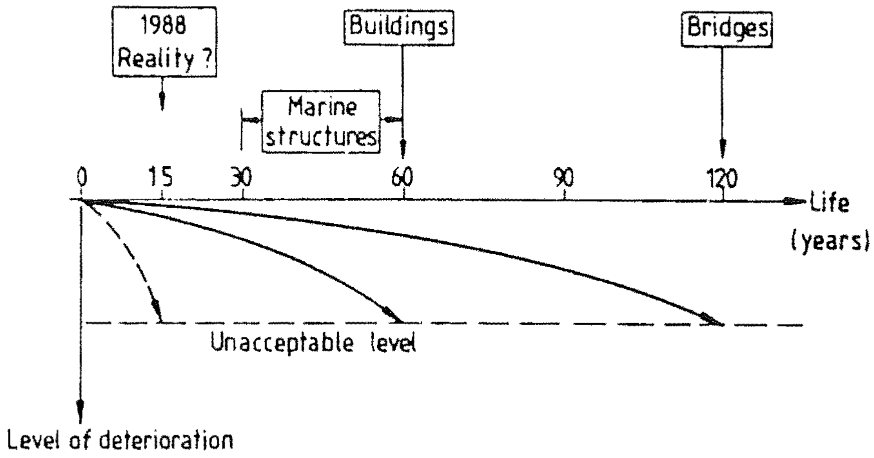
Fig. 5.2: Design Chart for Durability (1)



Concrete Deck Slabs

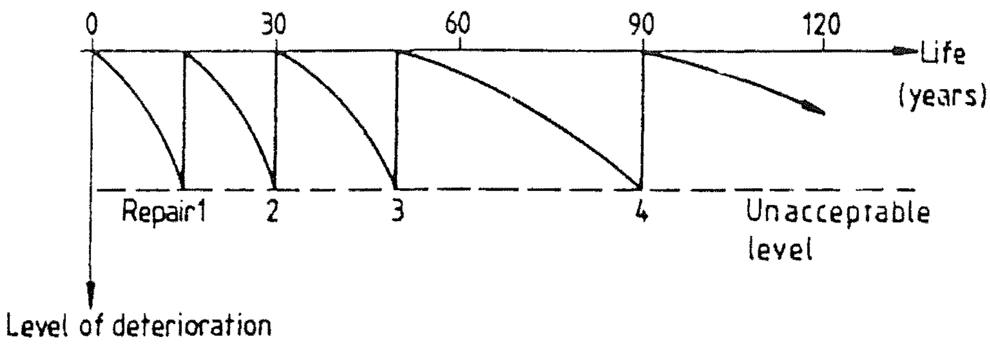
The cover to the reinforcement in all the deck slabs is given as 40 mm with a 5 mm negative tolerance on cover. The grade of concrete is 25 MPa. If other factors, such as the fixing of reinforcement and compacting concrete are considered, the 40 mm specified can easily tend to 30 mm. Therefore from Fig. 5.2 the time for carbonation to reach reinforcement is given as 100 or more. Furthermore, the time for chlorides to reach the rebars is 1.5 - 2 years. Chloride penetration would necessitate regular routine inspection every year to assess the condition of the deck and the amount of work needed for repair. This in itself would fall under routine maintenance. Addition protection was applied to enhance the durability of rebars. This required improving the concrete by adding penetration resistance admixtures or cement replacements (pfa and slag).

Fig. 5.3: Design Life for Structures (1)



Therefore the time to damage (t) was estimated as being 10 years. The 10 year period is adopted in this report to be a realistic value for structures to reach an unacceptable level of deterioration as illustrated in Fig. 5.3. Figure 5.3 illustrates that structures start to deteriorate from the time they are constructed until they reach an unacceptable level within their design life. Figure 5.4 shows that, in such rapidly deteriorating structures, a repair can restore the structure to its former condition, with a lower deterioration rate and repair frequency thereafter. Although the design life for bridges in Fig. 5.3 is given as 120 years, the one adopted for analysis in this study is 60 years with refurbishment varying depending on the rate of deterioration of the individual major structural components.

Fig. 5.4: Repeated Repairs Over the Life of a Structure (1)



5.6 TIMBER STRUCTURES (GLULAM BEAMS)

A similar approach to that carried out when calculating the design life of a reinforced structure, could be applied in predicting the service life of glulam beams. It is possible to calculate the service life of timber by defining the root cause of the deterioration when wood is exposed to the external environment. It should be noted that in the absence of decay, wood exposed to the weather, can and does, last for centuries. Once the causes are established, then measures to deter or eliminate further deterioration should be determined. The protective measures will be the basis of choosing the service life of the timber structure. Finishes applied to guard against deterioration of wood serve as the protective measures.

5.6.1 Weathering of Wood

Wood exposed to the external environment without protection undergoes:

1. Photodegradation by utraviolet light,
2. Leaching, hydrolysis, and shrinking and swelling by water, and
3. Discoloration and degradation by decay micro-organisms.

For glued-laminated members the penetrating finishing method is used by using preservative oils (creosotes). According to data from observation of researchers, (ROBERT 1982), the maintenance period of this surface finish is 5-10 years if original colour is to be renewed; otherwise no maintenance is required. The advantage with this type of finish is its maintenance cost which is low to nil. The life span of timber treated with this sort of preservative is 40-80 years. A 60 year study period is adopted and it falls well within the the life span. Rehabilitation for timber structures is also once for every 30 years except at the end of the study period.

5.7 RISK ANALYSIS

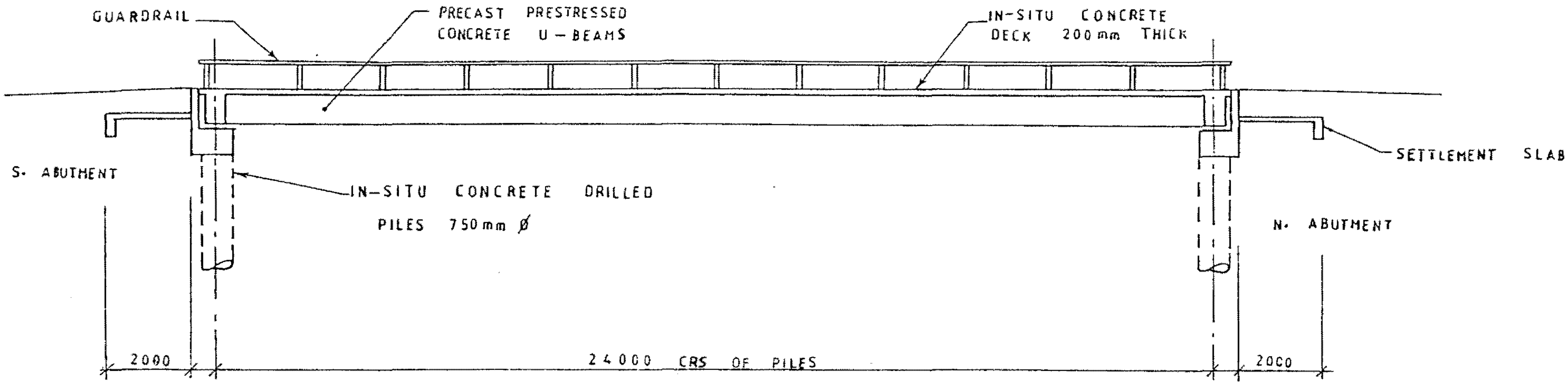
5.7.1 General

It was earlier mentioned that life cycle costing deals with the future and that the future is unknown. Recurrent costs such as maintenance, replacement and cleaning costs are only estimates. Similarly, the rate of exchange (i.e the discount rate) between future costs and their present values, replacement cycles or individual components, and the life cycle of the project cannot be assessed with certainty.

There are currently two techniques in use in dealing with risk analysis and these are:

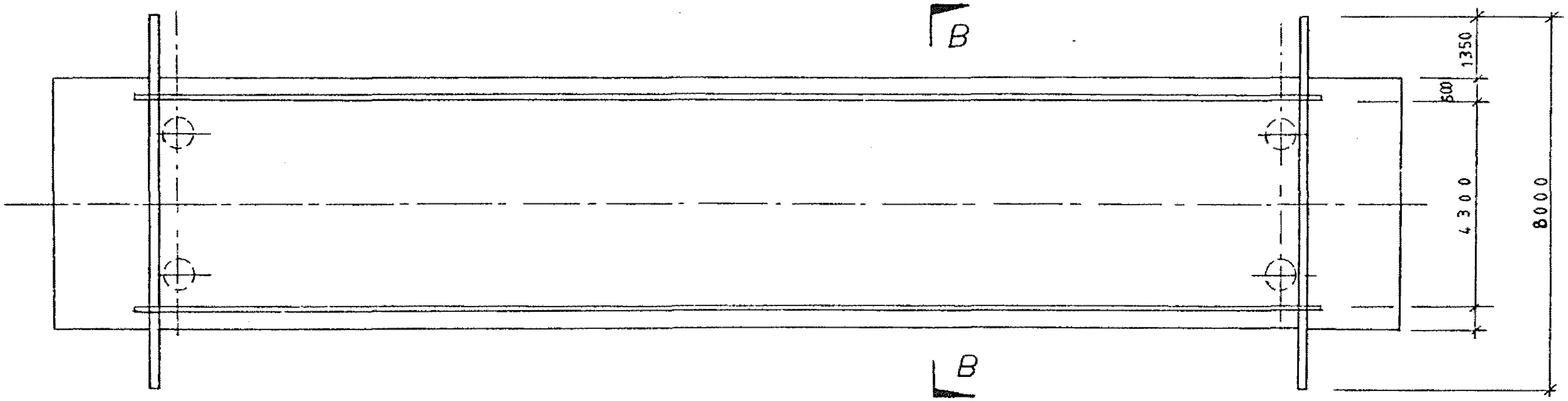
1. Sensitivity analysis, and
2. Probability analysis/Monte Carlo simulation.

The distinction between them is that sensitivity analysis does not require that a probability distribution be associated with each risk element. In addition, sensitivity analysis is essentially a univariate approach that identifies the impact of a change in a single parameter value within a project, while fixing all other parameters at their best-guess estimates, to observe their effect on the cost measure. The probabilistic approach, however, is a multivariate approach in which all factors subject to risk and uncertainty vary at the same time. There are advantages and disadvantages in both techniques. The primary advantages of sensitivity analysis are flexibility, versatility, and simplicity. It can accommodate almost any objective measure (e.g. TLCC). It is easily adapted for computer applications. Sensitivity analysis has a disadvantage of being univariate. In this study only sensitivity analysis is adopted as it is an easily applicable and understood risk analysis technique. The primary advantage of probabilistic analysis is that it is multivariate, and so gives an overall assessment of the likely risk exposure in a particular project. The disadvantages of this approach are the complexity and difficulty in disentangling the risk impact of any one uncertain factor.



ELEVATION

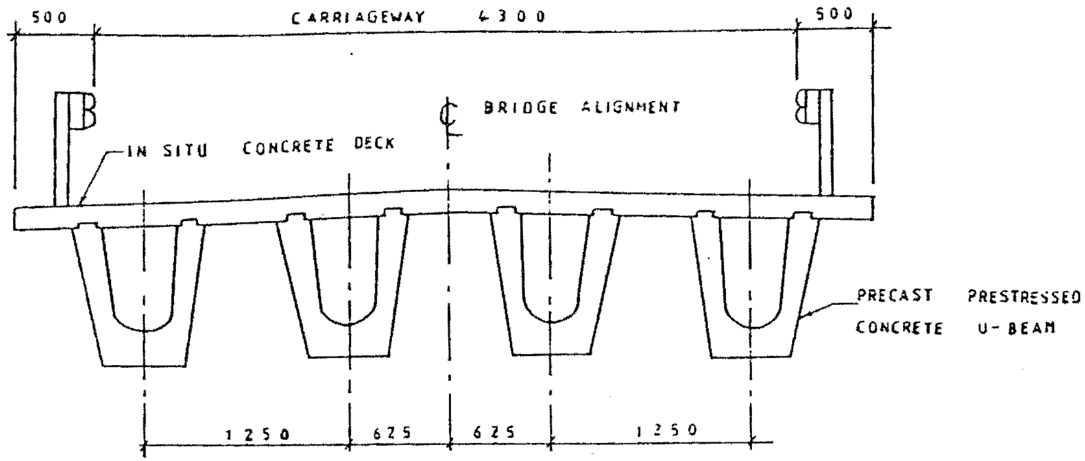
SCALE= 1:100



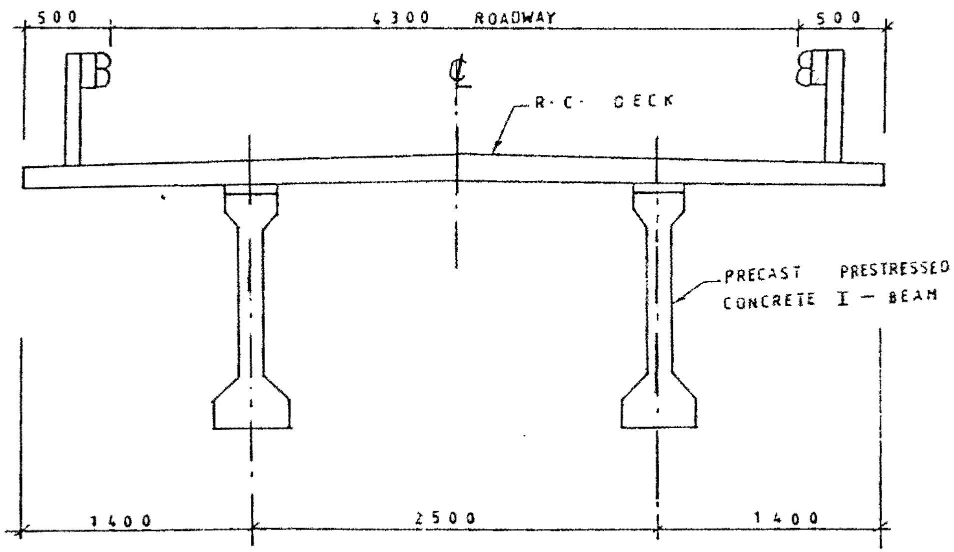
PLAN OF COMPOSITE CONCRETE BRIDGE

SCALE = 1:100

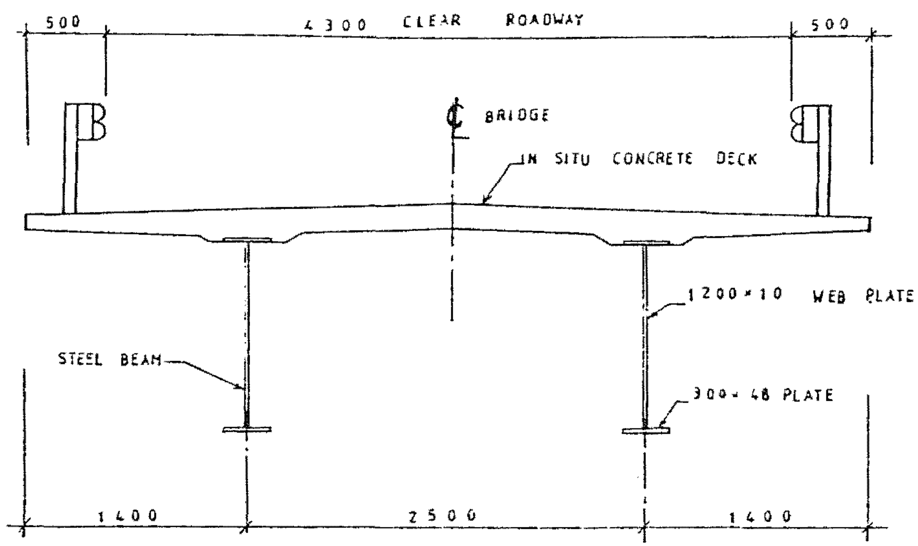
Fig. 5.5



SECTION: B-B

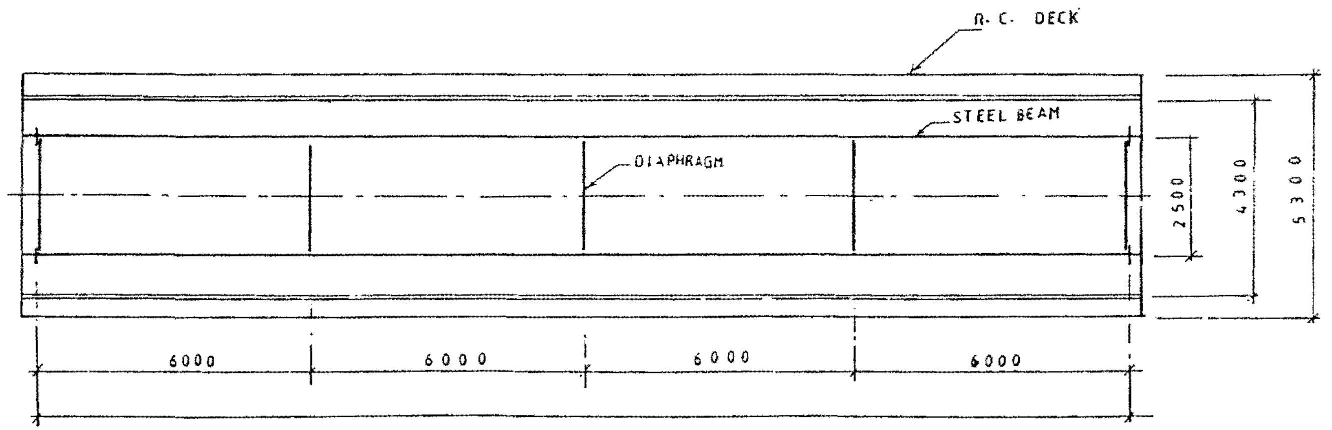


BRIDGE WITH CONCRETE I- BEAM



GENERAL CROSS SECTION

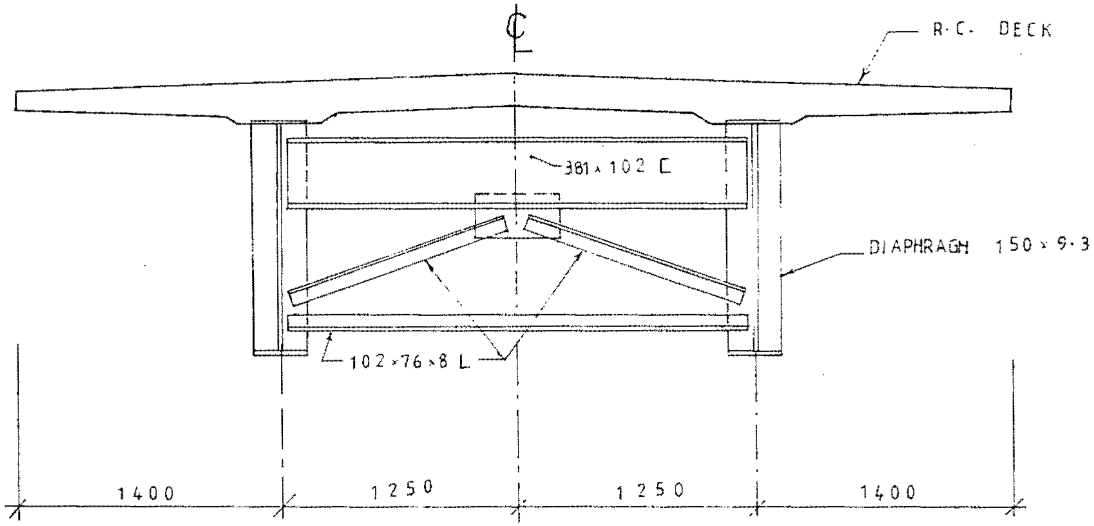
SCALE = 1:20



FRAMING PLAN OF STEEL BRIDGE

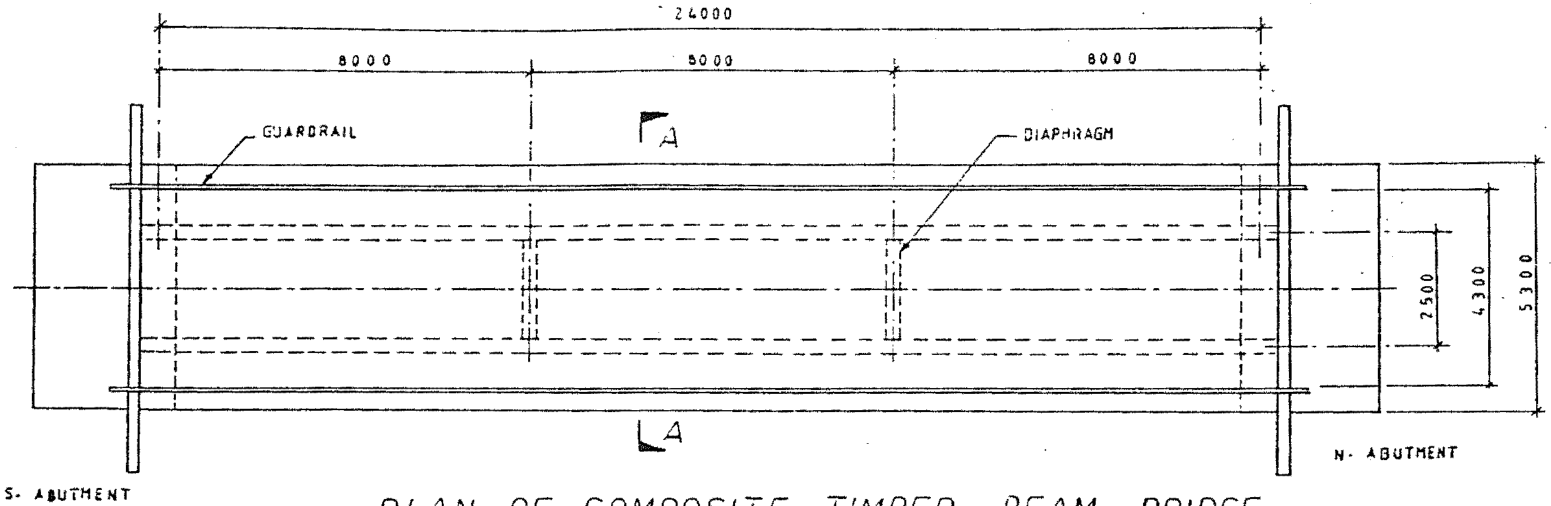
SCALE 1:100

Fig. 5.6



X-SECTION DETAIL OF STEEL BEAM

Fig. 5.6



PLAN OF COMPOSITE TIMBER BEAM BRIDGE

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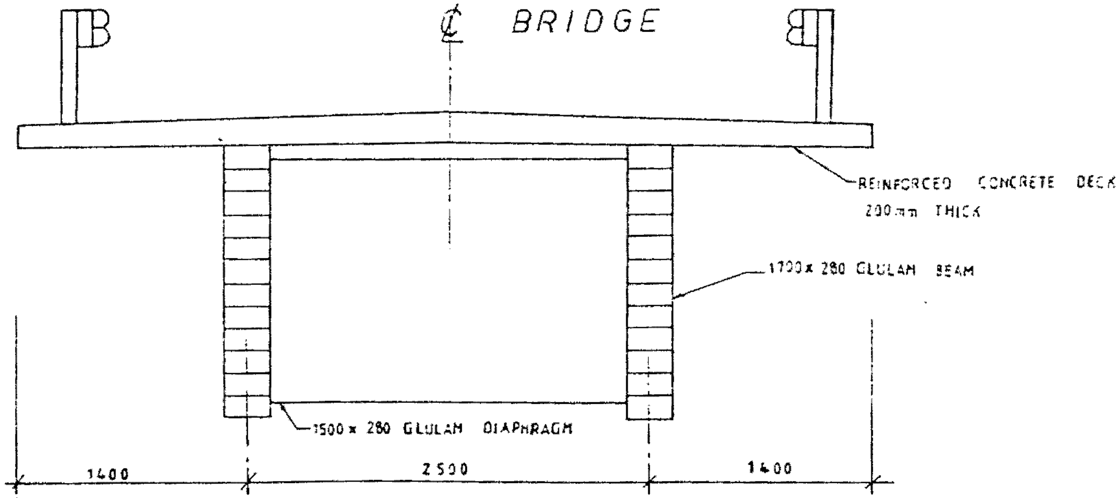

SECTION: A-A

SCALE = 1:20

Fig. 5.7

5.7.2 Sensitivity Analysis Results of the Bridge Types

These analyses are to ascertain how variation in a single parameter can affect the total sum of life cycle costs. This is done by altering one parameter while leaving all the others constant.

The parameters considered in the analyses are:

(a) discount rates,
(b) study period,
(c) material and labour costs.

A sensitivity analysis of a single lane bridge is carried out by looking at the three parameters mentioned above. Below are the results of the analysis from each of the single parameters considered. The input data for these analyses are set out in detail in Appendix A and the method of analysis is set out in chapter 4.

(a) Discount rates

Table 5.5: Total Life Cycle Costing of Single Lane Bridge with Varying Discount Rates and Study Period of 60 Years

Discount Rates	TOTAL LIFE CYCLE COSTS		
	Concrete (U-beam)	Steel	Timber
0	$286,711	$349,906	$336,770
5%	$168,581	$178,548	$176,057
10%	$142,347	$139,874	$139,872
15%	$133,706	$126,822	$127,701
20%	$129,868	$120,952	$122,239

Table 5.5 shows the variation of TLCC with discount rate. A 10% discount rate with a 60 year design life for a bridge was taken as a basis for the analysis in this study.

Reducing the discount rate to 5 and 0% increases the TLCC of concrete bridge type by about 18 and 101% whereas increasing its discount rate to 15 and 20% reduces it TLCC by about 6 and 9% respectively.

For a steel bridge, reducing the discount rate to 5 and 0% increases its TLCC by about 28 and 150% whereas for a timber bridge it increases to 26 and 141% respectively. Increasing the discount rate to 15 and 20% reduces the TLCC of steel and timber bridges by about 9 and 13% respectively.

Table 5.6: Total Life Cycle Costs of Single Lane Bridge with Varying Discount Rates and a Study Period of 60 Years

Discount Rates	TOTAL LIFE CYCLE COSTS		
	Concrete (I-beam)	Steel	Timber
0	$250,439	$349,906	$336,770
5%	$132,309	$178,548	$176,057
10%	$106,075	$139,874	$139,872
15%	$ 96,434	$126,822	$127,701
20%	$ 93,596	$120,952	$122,239

Table 5.6 shows the variation of TLCC with discount rates. The only difference from the previous analysis is in the concrete bridge, where the analysis is carried out with the use of an I-beam instead of the U-beam.

Reducing the discount rate to 5 and 0%, increases the TLCC of this type of concrete bridge by about 25 and 36% respectively, and for the steel bridge by about 28 and 150% respectively whereas for a timber bridge the rates are about 26 and 141% respectively. Increasing the discount rates to 15 and 20% reduces the TLCC of all the bridge types by about 8 and 13% respectively.

(b) Study period

Table 5.7: Total Operating Costs of a Single Lane Bridge with Varying Study Periods, Discounted at 10%

YEARS	TOTAL LIFE CYCLE COSTS		
	Concrete (U-beam)	Steel	Timber
20	$136,130	$130,108	$130,815
30	$138,867	$135,075	$135,336
40	$141,841	$138,907	$138,997
50	$142,347	$139,645	$139,669
60	$142,347	$139,645	$139,669
70	$142,482	$140,058	$140,045
80	$142,496	$140,072	$140,059
90	$142,502	$140,078	$140,065
100	$142,504	$140,080	$140,067

Table 5.7 shows variations of TLCC with design life. The analysis is based on a 60 years design period. For the concrete bridge, reducing the design life to 50, 40, 30 and 20 years reduces its TLCC by about 0, 0.4, 2.4, 44% respectively. For the steel bridge, following the same order of design life reduction as in the concrete bridge above, the TLCC is reduced by about 0.2, 0.7, 3.4 and 7% respectively. Similarly, for the timber bridge, its TLCC is reduced by 0.1, 0.6, 3.2 and 6.5% respectively.

Increasing the design life of concrete, steel and timber bridge types to 70, 80, 90 and 100 years increases their TLCC to 0.1% for all of them.

(c) Material and labour costs

Table 5.8: Total Life Cycle Costs of a Single Lane Bridge With Percentage Increase in Costs of Labour and Materials, Discounted at 10%

Percent. Increase 20%	TOTAL LIFE CYCLE COSTS		
	Concrete (U-beam)	Steel	Timber
Labour	$147,140	$144,234	$142,213
Steel Materials	$148,590	$147,981	$141,726
Concrete Materials	$145,294	$140,693	$140,691
Timber Materials	$144,756	$141,148	$149,952

Table 5.8 shows the variation of bridge types TLCC with material and labour costs. Increasing the labour cost to 20% of concrete, steel and timber bridge types, increases their TLCC by about 3, 3 and 2 respectively.

Increasing the cost of steel material to 20% of concrete, steel and timber bridge types increases their TLCC by about 4, 6 and 1% respectively. If, on the other hand, the cost of concrete material is increased to 20%, then the TLCC of concrete steel and timber bridge types is increased by 2, 1 and 1 respectively. However, increasing the cost of timber material by 20% increases the TLCC of these bridge types of 2, 1 and 7% respectively.

5.8 DISCUSSION

The results of the bridge project clearly indicate how the order of ranking alternative project options can vary with changes in a single parameter. The results in Table 5.5 show variation of TLCC with different discount rates. For discount rates less than 10% the concrete bridge ranks as the best option in terms of cost, as it has the lowest cost. However, with a 10% discount rate, a timber bridge ranks as the best option. Furthermore, with a discount rate greater than 10% it is still the best option.

If, however, the concrete U-beam is replaced with an I-beam, the order of ranking can be affected dramatically. For example, the results in table 5.6 show that the concrete I-beam comes out as the best option irrespective of the discount rate used, the other alternative bridge types retaining their ranking order as in table 5.5.

The sensitivity analysis results show that TLCC is significantly sensitive to discount rate compared with changes in design periods, material costs and labour costs.

The relative costs of alternative bridge options are also largely affected by changes in certain parameters. For example, taking the least cost as a reference value, the results in table 5.5 show a relative percentage difference of 17 and 22 relative to the least cost for a 0% discount rate. For the other discount rates the relative differences are 1 and 5 on the average. However, the results in table 5.6 show percentage differences of 33 and 32 on average throughout.

When looking at the relative costs from the given alternative project options, for example, with variation in project design life as in table 5.7 the differences are not as remarkable. For 40 years upwards the percentage difference is 2 and for 20 years and 30 years this comes to 1 and 4 percent on the average.

With changes in costs for labour and materials, table 5.8, the relative costs of the alternative project options are on average 2 and 4% relative to the least cost project option.

5.9 SUMMARY AND CONCLUSION

The various resources required for construction and maintenance activities of bridges, together with their respective costs, has generally been reviewed. Guidelines have been set out on how to arrive at service life of a project as well as its costs. Such information is used as a basis for economic evaluation of the project in this study. The life cycle costing technique is taken as a suitable method of economic evaluation that facilitates incorporation of initial and future costs in its analysis. Efforts have been made to identify factors that lead to degradation of structural materials and how to remedy them.

In conclusion it has become apparent from the results of the analyses that the concrete I-beam bridge is the best option from the four bridge types considered.

CHAPTER SIX

ROAD PROJECT

6.1 INTRODUCTION

In this study two road cases were considered for analysis. Case one looked at roads in New Zealand and the other one at roads in Kenya. This paper presents an economical assessment of the whole life costs of the road pavement types considered in each case by using a VP-Planner Spreadsheet run on an IBM personal computer. This package is used to calculate the Total Life Cycle Cost (TLCC) of a road. TLCC for a road in this study consists of road construction, maintenance and user costs for each year. All these costs are then discounted back to the base year and summed over the life of the road to obtain the TLCC. The spreadsheet requires the following basic input:

1. Major construction components,
2. Construction unit costs,
3. Vehicle operating unit costs,
4. Traffic volumes,
5. Vehicle loads,
6. Maintenance policy, and
7. Maintenance unit costs.

A cost data spreadsheet was fist set up. Typical roads were taken for analysis. Quantities of their construction works were estimated and thus the costs of performing construction activities were determined. Having estimated construction costs, the deterioration of the road was estimated in relation to the maintenance policy selected as well as traffic flow. The maintenance costs were estimated for each year of the analysis. Road user costs were estimated from traffic volume using vehicle fixed cost and vehicle operating costs. Fixed costs and vehicle operating costs were then used together with traffic forecasts to give the total vehicle operating costs for the year in question. The costs calculated for each year of the study period were discounted back to the base year at a discounted rate, suitable for each country considered, and the total cost was obtained by summing these discounted costs.

For proper economic project evaluation, a number of alternative proposals were analysed for a given pavement type and thus it facilitated selection of the best option from a number of alternative solutions. Comparison is based on pavement types with identical characteristics, i.e. alternative pavements with the same physical characteristics, traffic volume and design period.

As part of the assessment, sensitivity of the Total Life Cycle Cost (TLCC), to changes in discount rate, fuel costs, and design period were carried out. The accuracy of this analysis was limited by the lack of comprehensive data available, however, where reasonable data were not available approximate values for the principal variables were adopted.

6.2 ROAD CONSTRUCTION

6.2.1 Pavement Types

Many pavement types are constructed with a view of providing a traffickable surface in all kinds of weather. The materials used to make such pavements depend upon many factors, which include their availability and cost, the importance of the road, the volume and type of traffic, the climatic and topographic conditions of of the area, and the type of base or foundation upon which the pavement is to be laid.

Roads are classified under two major groups according to their pavements finished surface: unsealed and sealed pavements. These are further subdivided into pavement types.

Unsealed roads include:

(i) macadam construction,
(ii) natural gravels,
(iii) crushed rock,
(iv) sandy clay,
(v) stabilised soil.

Sealed roads include:

(i) bituminous pavements (flexible pavement),
(ii) cement concrete (rigid pavement).

In this study only macadam construction and natural gravel are considered under unsealed roads whereas under sealed roads both types are assessed.

6.2.2 SEALED (PAVED) ROAD

6.2.2.1 Flexible pavement

For sealed roads, a number of pavement layers are used. Each layer is specified by its thickness and material type. The strength of each layer is specified in terms of:

(a) Califonia Bearing Ratio (CBR), and
(b) Strength Coefficient for asphalt surfacings.

The layers for flexible pavements comprise of:

(i) bituminous surfacing,
(ii) base,
(iii) sub-base,
(iv) subgrade.

The subgrade is the upper layer of natural soil, either in-situ or in fill.

1. Bases and sub-bases

For flexible pavements, the principal function of the base and sub-base is to distribute the stresses imposed by traffic. The total thickness of the base and sub-base should be sufficient to reduce the stresses on the subgrade below the limit that the soil will accept repeatedly without excessive deformation deriving either from shear failure or from compaction under traffic. The materials commonly used in making bases and sub-bases are:

(i) natural soils and gravels,
(ii) crushed stones,
(iii) stabilised soil (cement, lime and bitumen).

2. Bituminous surfacing

The uppermost layer of pavement is defined as the wearing course and its function is to distribute the high stresses imposed at the tyre/road surface interface, waterproof the pavement, resist the abrasive action of vehicle tyres and provide adequate skid resistance. The materials used in making the wearing course consist of crushed rock aggregates that are bound with either tar or bitumen to form a tar macadam or bitumen macadam (bituminous surfacing).

6.2.2.2 Cement concrete pavements (rigid pavements)

The running surface of rigid pavement is of concrete. It comprises concrete surfacing and base supported on the subgrade. Concrete pavements may be reinforced or unreinforced; if reinforced the steel may be of individual bars or welded mesh. The slabs may contain several different types of joints or they may be unjointed or continuous.
Reinforcement in concrete pavements is optional as there is no difference in the required thickness of slab for reinforced or unreinforced construction. The function of the reinforcement is to limit the size of the surface cracking so that aggregate interlock is preserved. For this reason reinforcement is placed close to the upper surface of the slab. In slabs of not less than 150 mm thick the cover over the steel is 60 mm ± 10 mm and in thinner slabs 50 mm ± 10 mm. The concrete road slab consists of standard mixtures of graded aggregate, cement and water. Materials suitable for the base are non-plastic gravelly soils, cement (or lime-stabilised soils), or lean concrete.

6.2.3 Unsealed/Unpaved Road

For gravel and macadam construction only one layer of pavement is used and, for earth roads, there is no pavement.

6.2.3.1 Macadam pavement

Macadam (water-bound) pavement consists of a layer of broken stone of about 60 mm gauge, bound with stone of 20 mm gauge, then watered and rolled to the required cambered surface.

6.2.3.2 Natural gravel

Natural gravel occurs in different forms in many parts of the world. The best type is one which contains a reasonable percentage of fine binding material such as clay or loam; those deficient in this respect may be corrected by the addition of binders. In tropical regions natural gravel deposits consists of latteritic gravels, alluvial gravels, detrital gravel and sands. Natural gravel pavement does not require proper design. The thickness needed for gravel surfaced roads is based on local experience. The standard layer thicknesses of granular surfacing vary from 100 to 200 mm.

6.3 ROAD MAINTENANCE

6.3.1 General

The object of all maintenance is to conserve the assets represented by preserving the road structure and its associated drainage systems in good condition. Furthermore, in road maintenance it is essential to maintain the flow of traffic in defined conditions. Secondly, the safety of road users should be ensured. Thirdly, the comfort of users should not be overlooked and finally, there are aesthetic considerations to preserve the appearance of the road in relation to the surrounding countryside. To ensure that the financial resources available for maintenance are in line with those available for construction an estimate should always be made of the recurrent maintenance costs that will follow the construction or improvement of a road. Apart from construction and maintenance costs, it is important to take into account the road user costs. Combining these three costs together throughout the economic design life of a road, gives the total life cycle costing.

Road maintenance can be divided into three types:

(i) routine maintenance,
(ii) periodic maintenance, and
(iii) rehabilitation or upgrading.

This chapter deals with all these three different types of road maintenance.

6.3.2 Routine Maintenance

This consists of those work items regularly performed by maintenance personnel throughout the year.

The activities carried out under routine maintenance are:

(i) Cleaning out ditches; removing weeds, silt and rubbish,

(ii) Re-excavation of ditches to correct size and shape,

(iii) Filling potholes and ruts with material similar to those used for the surface layer, and compacting them,

(iv) Maintaining the correct surface camber by retrieving loose material from the edges and respreading and compacting it,

(v) Repairing erosion channels formed on the running surface, the shoulders or the ditch slopes,

(vi) Cutting vegetation on the shoulders, between the shoulders and side ditches, and in areas where visibility is hampered,

(vii) Cleaning silt and debris from culverts, fords and other structures to allow a free flow of water,

(viii) Removing corrugation,

(ix) Repairing, cleaning and replacement of traffic signs, distance makers, and repainting of road markers.

6.3.3 Periodic Maintenance

This consists of more extensive maintenance operations that are necessary every few years.

This includes the following:

(i) Reshaping and where necessary raising the level of the crown of earth roads above the surrounding environment,

(ii) Regravelling gravel roads,

(iii) Reshaping drainage ditches,

(iv) Resealing of asphaltic treated surface roadway,

(v) Applying a new overlay of asphaltic concrete.

6.3.4 Rehabilitation or Upgrading

The activities involved in here are capital improvement and include the following:

(i) pavement reconstruction,
(ii) widening, and
(iii) realignment.

6.4 ROAD USER COSTS

6.4.1 General

In this project there are three main areas of costs that are considered in the economic evaluation, viz.

(i) road construction cost,
(ii) road maintenance cost, and
(iii) road user cost.

Construction costs are incurred while the road is being built and reconstruction costs are incurred in years when upgrading takes place. Road maintenance and user costs are incurred in all years that the road is open to traffic. There is significant interaction between the various costs that are associated with a road project. The road user cost, for example, depends on the numbers and types of vehicles, the geometric design standards and on the condition of the road surface. The road maintenance cost will depend on the condition of the road surface, which, in turn, is dependent on the initial road construction standard, and maintenance costs in previous years, the environment and the number and types of vehicles using the road. The TLCC of a road project is found from the sum of the construction, road maintenance and road user costs for each year, discounted back to the base year at the appropriate rate. Overhead costs in this study are either indicated in the schedule of rates and quantities or simply incorporated in the costs of the activities.

6.4.2 Construction Costs

In this study only the major activities were considered in the analysis both for sealed and unsealed roads. The cost of minor activities were either taken as a small percentage of the construction cost or neglected as their exclusion will have no significant effect in the analysis. Five to ten per cent of the major construction cost was allowed to cover minor construction works. The cost of the works involved in the construction of the road projects in this analysis were based on the available data from each country, and where there was a lack of data, as in Kenya, data from international bodies such as the World Bank, International Labour Organisation and the like were used.

6.4.2.1 Unsealed roads

The major works considered for costing in the construction of unsealed roads consist of:

(a) Clearing and grubbing

(b) Excavation

(i) boulder removal or rock excavation,
(ii) excavation to fill and to spoil,
(iii) loading and unloading.

(c) Drainage and sloping

(d) Camber formation and compaction

(e) Culvert laying

(f) Gravelling

6.4.2.2 Sealed roads

For sealed roads the activities considered for costing include:

(i) site clearance,
(ii) earthwork,
(iii) pavement,
(v) surfacing,
(vi) drainage.

6.4.3 Maintenance Costs

In this study maintenance costs are calculated by first identifying the activities involved in maintenance of the road pavement type. The frequency with which maintenance activities are performed are established either from experience, or the maintenance policy of the country of which the project is analysed. The amount of maintenance required and also the cost of carrying out the work was based on unit costs, productivity and labour costs. Where such data were not available, as in Kenya, data from the International Labour Organisation, World Bank and UNESCO was used.

1. Sealed roads

The activities involved in the maintenance of sealed roads consist of:

(i) patching,
(ii) surface dressing/resealing,
(iii) overlaying, and
(iv) routine maintenance.

2. **Unsealed roads**

For unsealed roads maintenance consists of:

(i) regrading,
(ii) regravelling of gravel roads,
(iii) resurfacing, and
(iv) routine maintenance.

6.4.4 Road User Costs

Road user costs are made up of two major components:

(i) Travel Time Costs - the cost to the vehicle occupants of time spent travelling the section of road.

(ii) Vehicle Operating Costs - the costs of operating a vehicle travelling the section of road.

6.4.4.1 Travel time costs

The cost of the time spent by vehicles and their occupants travelling a section of road is calculated using the general equation:

Total Time Cost = Σ (Time value for occupants and Freight x Journey time)

The basic factors needed for this calculation are measurement of traffic volume and journey time.

6.4.4.2 Vehicle operating costs

Vehicle Operating Costs (VOC) are dependent on vehicle type, volume of traffic, length of road sections, pavement roughness and speed. Most of the studies that have been conducted indicate a large increase in vehicle operating costs with increasing road roughness which in turn depend on traffic volume. In this study the operating costs were calculated with an element of road roughness, especially for roads in developing countries as shown in the appendix C. The operating costs for New Zealand roads were derived from vehicle utilization together with the costs necessary to maintain the car on the road.

They are calculated as:

Vehicle operating costs (VOC) = Σ (Operating cost x Traffic Volume x Distance)

VOC form the largest single component of total transport costs not only in developing countries but also in developed countries. According to PTRC 1985 it was estimated that VOC in developing countries make up 70-90% of total transport system costs in any type of economic analysis.

Vehicle Operating costs can be subdivided again into: (a) Fixed costs and (b) Running costs.

(a) Fixed costs consist of:

(i) new vehicle price,
(ii) annual relicensing fee,
(iii) comprehensive insurance,
(iv) warrant of fitness
(v) interest on outlay, and
(vi) depreciation.

(b) Running costs consists of:

(i) fuel consumption,
(ii) tyres,
(iii) parts consumption, and
(iv) maintenance labour-hours.

6.5 ROAD DETERIORATION

The rate at which roads deteriorate will depend on whether they are earth, gravel or paved and also on the traffic volume.

An unsealed road's deterioration is defined as a measure of:

(i) surface roughness,
(ii) rut depth,
(iii) depth of loose surface material,
(iv) Rainfall, and
(v) gravel loss.

A sealed road's deterioration measurements include:

(i) surface roughness,
(ii) rut depth, and
(iii) amount of cracking and patching.

In carrying out repair and maintenance on roads in this study, the amount of work involved and the time interval for repairs were based on the limits set on the deterioration measurements. Where standard limits were not available, estimates were used.

6.6 NEW ZEALND ROADS

6.6.1 General

A typical road project is considered for analysis based on New Zealand National roads standards. The purpose, for this study, as with the other projects, was to carry out an economic assessment of flexible and rigid pavements using the Total Life Cycle Costing technique.

Furthermore, it was important to investigate the sensitivity of TLCC to changes in discount rates, fuel costs, labour costs, and project design life. The accuracy of this analysis, as mentioned earlier, was limited by lack of comprehensive data; however, where data were not available estimates based on my experience were used to obtain a range within which approximate values would lie.

6.6.2 Design

The road design considered in the analysis is based on New Zealand National Roads Standards Specification. It is a 5 km section of two-lane, two-way carriageway carrying 1205 vehicles per day. The heavy commercial vehicles are taken to be 21% of the total traffic volume. The design lives for flexible and rigid pavements are 20 and 40 years respectively. The sub-grade CBR of 8% was taken in the design. The carriageway width of 7.3 m, including 2.5 m gravel shoulders was used. The data used for design in the analysis is given in Appendix B and shown in tables (B1, B2.1, B2.2, B3.1, and B3.2).

6.6.3 Construction Costs

The major construction works considered in the analysis are earthworks and pavement. The operations under these two major works are given in Appendix B together with their inputs, productivities, duration and labour costs in table B4. The equipment cost estimates are worked out in table B5. In order to arrive at the construction cost estimates shown in tables (B6.1 to B6.4), the data from tables B4 and B5 were used. Cost for equipment plus their productivity together with labour costs were obtained from New Zealand Construction Costs (1989). Data for material costs were available from material suppliers and contractors, and also from National Roads Boards (N.Z.).

Operations such as establishment, drainage and other miscellaneous activities have not been included in the analysis.

6.6.4 Maintenance Costs

Operating costs of a road project incurred after construction depend mostly on the sort of material used in the construction and the volume of traffic using the road.

Maintenance works for flexible pavement, as was mentioned earlier, in section 6.4.3, consist of:

(i) patching,
(ii) resealing,
(iii) overlaying,
(iv) reconstruction, and
(v) annual maintenance.

In this study all these operation were considered for analysis and the maintenance costs for the various flexible pavement types are given in tables (B7.1 and B7.2) Appendix B.

Maintenance works for rigid pavements considered in this study consist of:

(i) retexturing,
(ii) surface patching,
(iii) crack stitching,
(iv) bay replacement,
(v) joint replacement,
(vi) joint sealing,
(vii) reconstruction, and
(viii) routine maintenance.

Maintenance costs for rigid pavements are show in tables (B7.3 and B7.4) Appendix B.

6.6.5 Road User Costs

In this study only vehicle operating costs were considered for analysis; other costs such as crew time, passenger delay, accident and comfort were not included in the analysis. Vehicle operating cost (VOC) items, as given in section 6.4.4.2, were taken for analysis. Details of the vehicle data used in the analysis are given in Appendix B. The data for VOC were obtained from N.Z. car dealers, service stations and the New Zealand National Roads Board. The annual growth rate of traffic was taken to be 3 per cent with a 10 per cent discount rate. Table B13 shows the total vehicle operating costs for the flexible pavement at 20 years study period, as well as for the rigid pavement at 40 years study period.

6.6.6 SENSITIVITY ANALYSIS

6.6.6.1 General

Having determined the costs of construction, maintenance and road user costs the total life cycle costs for the various alternative pavement types were obtained by summing these three costs together. Simple sensitivity analyses of the total life cycle costs were carried out by varying the discount rate, design period and fuel cost. Discount rates of 10, 12, 15, 18 and 20 per cent and design periods of 10, 15, 20, 30 and 40 years as well as fuel cost increases of 5, 10 and 15 per cent were studied.

Table 6.1: Sensitivity of Total Life Cycle Costs to Discount Rates for New Zealand Road Project

DISCOUNT RATE	TOTAL LIFE CYCLE COSTS			
	FLEXIBLE PAVEMENT 20 Yrs		RIGID PAVEMENT 40 Yrs	
	Alternatives (A)	Alternatives (B)	Alternatives (C)	Alternatives (D)
10%	265782148	265773884	305867016	305970177
12%	225627250	225547593	249631680	249630598
15%	180284158	180200724	192033103	191927023
18%	147444197	147386313	153669478	153494885
20%	130440335	130408542	134752836	134545076

Table 6.2: Sensitivity of Total Life Cycle costs to Design Periods, Discounted at 10% for New Zealand Road Project

DESIGN PERIOD (Years)	TOTAL LIFE CYCLE COSTS			
	FLEXIBLE PAVEMENT 20 Yrs		RIGID PAVEMENT 40 Yrs	
	Alternatives (A)	(B)	Alternatives (C)	(D)
10	157917149	157909124	158799626	158737905
15	221702376	221694351	222514559	222466457
20	265782148	265773884	266509385	266554721
25			277897857	277946945
30			289848418	289938941
40			305867016	305970177

Table 6.3: Sensitivity of Total Life Cycle Costs to Fuel Cost Increase, Discounted at 10%, with 20 and 40 Years Design Life for Flexible and Rigid Pavements Respectively for New Zealand Road Project

FUEL COST INCREASE	TOTAL LIFE CYCLE COSTS			
	FLEXIBLE PAVEMENT 20 Yrs		RIGID PAVEMENT 40 Yrs	
	Alternatives (A)	(B)	Alternatives (C)	(D)
5%	266872204	266863974	307120045	307223330
10%	267962263	267954067	308373077	308476486
15%	269052321	269044160	309626109	309729641

KEY:

A = Flexible pavement (alternative B) with AP60 sub-base
B = Flexible pavement (alternative A) with AP40 and silty sand sub-base
C = Rigid pavement (alternative C) with reinforced concrete surfacing
D = Rigid pavement (alternative D) with plain concrete surfacing.

Note: The underlined figures in the tables above indicate the lowest cost option from the alternatives for a given parameter.

6.6.6.2 Discount rate

Variation of total life cycle costs with discount rates are shown in table 6.1. The analysis for roads in New Zealand is based on a 10 per cent discount rate with economic study periods of 20 and 40 years for flexible and rigid pavement respectively. The results in table 6.1 show that increasing the discount rate to 12, 15, 18 and 20 per cent reduces the total life cycle costs by about 15, 32, 45 and 51 per cent respectively for a flexible pavement.

Total life cycle costs for rigid pavement, using the same order of discount rate increment as in flexible pavements, reduces the total life cycle costs by about 18, 37, 50, and 56 per cent respectively.

6.6.6.3 Design period

Table 6.2 shows variation of TLCC with design periods. For flexible pavements reducing the design period to 15 and 10 years reduces both alternatives A and B by about 17 and 41 per cent respectively. For rigid pavements reducing the design period to 30, 25, 20, 15 and 10 years reduces the TLCC by about 5, 9, 13, 27 and 48 per cent respectively for both alternatives.

6.6.6.4 Fuel cost increase

Table 6.3 shows the variation of TLCC to fuel cost increase. Increasing the fuel cost to 5, 10 and 15 per cent increases the TLCC for both flexible and rigid pavements by about 0.4, 0.8 and 1.2 per cent respectively.

6.6.7 Discussion of results for New Zealand Roads

The results of the sensitivity analyses serve as a means of selecting the best project from alternative options. For example, the ranking of alternative project options may vary due to changes in a certain parameter. Furthermore, it might be that a certain project is cheaper to undertake, if its design life or service life is less or more than the set value. On the other hand, it might be that the sensitivity of total life cycle cost (TLCC) to particular parameters has no significant effect beyond certain limits.

The results of the sensitivity analyses for New Zealand roads show some interesting outcomes which clearly illustrate the points mentioned above.

By varying the discount rate, see table 6.1, the relative costs of the road types expressed in terms of percentage of the lowest cost of the bridge types for a given parameter, range from 0.003 to 0.05 per cent for flexible pavements and for rigid pavements the values of the relative costs range from nearly 0 to 0.15 per cent.

The relative costs of flexible pavements to changes in design life, see table 6.2, range from 0.003 to 0.005 per cent of the lowest cost of the alternative option whereas for rigid pavements the values of the relative costs range from 0.02 to 0.04 per cent.

A change in the cost of fuel in table 6.3 has no effect on the relative costs of alternative road types. The difference in relative costs remain constant as the fuel costs are increased, for example, for flexible pavements the percentage difference is 0.003 and for rigid pavements it is 0.03 per cent.

In this study it is apparent that TLCC is significantly sensitive to discount rate and design period. The sensitivity of TLCC to discount rate expressed as a percentage of the cost of each alternative project with a 10% discount rate ranges from 5 to 56 per cent.

6.7 KENYAN ROADS

6.7.1 General

This case study looks at a typical road project by using data available from Kenya. The aim for roads in Kenya, as in New Zealand, is the same, i.e to carry out an economic assessment using the Total Life Cycle Costing technique. This technique facilitates the exploration of all the works necessary during the design life of a road project. Such a technique is important in countries with limited resources and also for future planning. Construction, maintenance and road user costs are combined to get the total life cycle cost of a road project. Sensitivity analysis of TLCC to variations of discount rate, design period and fuel cost was studied. Most data used in the analysis here were from Kenya and where data were not available, information from international bodies such as World Bank, UNESCO and ILO, related to work carried out on Kenyan roads, were used.

6.7.2 Design

The road project complies with the standard Kenyan Ministry of Works specifications. The paved roads and unpaved roads taken for analysis have design speeds of 100 km/h and 80 km/h respectively. A 5 km length of road section was analysed. The terrain is taken to be generally flat, however, where there are slopes then they do not exceed 5%. The soil on this particular stretch of the road is taken to be fairly uniform and of granular lateritic, (murram), type having a CBR value of 8 per cent.

A design life of 20 years for both unsealed and sealed was used in the analysis with a 15% discount rate. For unsealed roads the traffic volume is taken to be 100 vehicles per day. For sealed road 880 vehicles per day with a 0.35 million equivalent standard axles (ESA) is assumed.

Two different pavement types were considered for analysis for unpaved roads; these included gravel and macadam pavements both having a single pavement layer of 150 mm thickness. For paved roads, two alternative pavement types were analysed, see tables (C6.1 & C6.2). The first alternative consists of 100 mm of lime stabilised sub-base, 130 mm of crusher-run base with a 25 mm triple surface seal. The second alternative consists of 180 mm crusher-run base with a 25 mm bitumen double surface seal. The shoulders are taken as 2.5 m wide gravel.

6.7.3 Construction Costs

The activities taken in working out the construction cost estimates are mainly:

(i) bush clearing,
(ii) grubbing and stripping,
(iii) excavation,
(iv) gravelling,
(v) pavement, and
(vi) surfacing.

The data used in the analysis for working out the construction costs were in agreement with that used by the Kenyan Ministry of Works. Whenever possible, data based on studies in Kenya has been applied and where such information was not available, data on similar activities carried out in other countries has been adopted and adjusted to suit Kenyan requirements. For example, productivity rates in this study were obtained from sources such as ILO, World Bank, IBRD and UNESCO, which have been concerned with civil engineering works particularly in developing nations.

Table C2 shows the detailed approach used in determining the activity durations together with their labour costs. By using the data from tables C1 and C2, it was possible to arrive at the equipment cost estimates given in table C3. Having determined the labour costs in table C2, equipment costs in table C3 and the cost of material from table C1, construction costs estimates for various pavement types were determined. Details of road construction cost estimates are given in tables (C4.1, C4.2, C5.1, C5.2, C7.1 & C7.2) in Appendix C.

6.7.4 Maintenance Costs

6.7.4.1 General

It was mentioned in section 6.5 that pavement deterioration largely depends on the volume of traffic and material used in the design. In order to estimate the maintenance costs, it is imperative to determine the amount of repair needed together with their repair intervals.

6.7.4.2 Gravel roads

An economic evaluation of road maintenance in Kenya, suggests that, given a standard level of routine maintenance and 30 rubber tyre draggings per year, the motor grading frequency for lateritic surfaces should be once for approximately 7000 vehicle passes; or once every 5 months for a 50 vpd road (HENRI, 1987). The frequency of regrading adopted in this study is once every 3 months. This took into account the difficulties that are usually encountered in developing nations, such as lack of funds and even spare parts for equipment, in carrying out the operations in time.

The loss of materials on unsurfaced roads is estimated to be of the order of 25 mm per year for every 100 vehicles using the road per day. The basic maintenance policy would be to carry out regravelling once every two to five years, according to traffic, the class of road, the materials, the climate, etc..

Resurfacing is carried out once in the design study. Annual routine maintenance costs in Kenya are of the order of 2.5% of the cost of construction when using a Lengthman contract system for a gravel road, (HODGES, 1975). Tables (C8.1 and C8.2) in Appendix C show details of the maintenance costs for unsealed roads.

6.7.4.3 Sealed roads

Maintenance operations carried out each year are surface and base patching, shoulder grading, shoulder mowing and drainage maintenance. Surface dressing or resealing is performed after each five years' trafficking. Overlaying, which is meant to strengthen the pavement, is carried out at the end of the design life or a few years before the end of design period as in this case.

The annual maintenance cost for sealed roads in Kenya is taken to be 5000 shillings per kilometre. This figure was arrived at by using the ideas from (ROBINSON, 1975), however, the figures used by in Robinson were modified to suit the current trend in Kenya.

Results showing maintenance costs for sealed roads considered here in the analysis for Kenyan roads are given in tables (C9.1 and C9.2) Appendix C.

6.7.5 Road User Cost

The data used in working out the relationship for vehicle operating costs other than fuel was obtained from (ROBINSON, 1975). A detailed procedure used in arriving at the VOC is given in Appendix C under the heading Kenyan Road User Costs.

The data for fixed and running costs for the vehicles used in this particular analysis were obtained from car dealers and garages in Kenya. The annual growth rate of traffic was taken to be 6 per cent with a 15 per cent discount rate. The life of all vehicles is taken as 20 years. Table C17 shows the actual and discounted vehicle operating costs for each year of service. The sum of all the vehicle operating costs discounted back to the base year gives the total vehicle operating cost which is likely to be incurred throughout the study period.

6.7.6 Sensitivity Analysis

6.7.6.1 General

Earlier on it was observed that TLCC can be sensitive to variations with certain parameters. A sensitivity analysis of TLCC to variations with parameters such as discount rate, design period and fuel cost, similar to that conducted with New Zealand roads, was carried out also with Kenyan roads.

6.7.6.2 Discount rate

Table 6.4 shows the variation of TLCC with discount rate. Discount rate variation was based on the 15 per cent rate used in design. Reducing the discount rates to 12 and 10 per cent increase the TLCC by approximately 24 and 46 per cent of the cost with the 15% discount rate of each alternative project respectively. However, reducing the discount rate to 18 and 20 per cent reduces the TLCC by about 18 and 27 per cent respectively for both unsealed and sealed roads.

Table 6.4: Sensitivity of Total Life Cycle Costs to Discount Rates, with 20 years Study Period for Kenyan Roads

DISCOUNT RATE	TOTAL LIFE CYCLE COSTS			
	UNPAVED		PAVED	
	Murram Pavement	Macadam Pavement	Triple Pavement	Double Pavement
10%	206625857	206477382	2073588652	2075909544
12%	176328224	176207332	1761352245	1763691941
15%	141943233	141860992	1407750154	1410107648
18%	116866733	116817929	1150586768	1152954544
20%	103812681	103783034	1017043333	1019415466

Table 6.5 Sensitivity of Total Life Cycle Costs to Design Periods, Discounted at 15% for Kenyan Roads

DESIGN PERIOD (Years)	TOTAL LIFE CYCLE COSTS			
	UNPAVED		PAVED	
	Murram Pavement	Macadam Pavement	Triple Pavement	Double Pavement
10	100894355	100780283	978791357	981174396
15	128233012	128120670	1263889673	1266272712
20	141943233	141860992	1407750154	1410107648
25	145227572	145146757	1407988896	1410346389

Note: The underlined figures in these tables indicate the lowest cost option from the alternatives for a given parameter.

Table 6.6: Sensitivity of Total Life Cycle Costs to Fuel Cost Increase, Discounted at 15% with a 20 year Design Life for Kenyan Roads

FUEL COST INCREASE	TOTAL LIFE CYCLE COSTS			
	UNPAVED		PAVED	
	Murram Pavement	Macadam Pavement	Triple Pavement	Double Pavement
5%	143251392	143153236	1414265163	1416630178
10%	144559552	144445479	1420780177	1423152714
15%	145867711	145737723	1427295185	1429675244

6.7.6.3 Design period

Table 6.5 shows the variation of total life cycle cost with the design period. The analysis here is based on a 20 year design period. Reducing the design period for both paved and unpaved roads to 15 and 10 years reduces the TLCC by about 10% and 29% respectively of the costs of each alternative project with 20 years design period.

Furthermore, increasing the design period to 25 years increases the TLCC by about 2 and 0.02 per cent for unpaved and paved roads respectively.

6.7.6.4 Fuel cost

Results in table 6.6 show the variation of TLCC with fuel cost increase. Increasing the fuel cost to 5%, 10% and 15% increases the TLCC by about 1%, 2% and 3% of the costs of each alternative project with 20 years design life respectively for unpaved roads whereas for paved roads it is halves the values of unpaved roads.

6.7.7 Discussion of the Results for the Kenyan Roads Analysis

The study conducted on Kenyan roads shows that the ranking of alternative project options is not affected by the changes applied during the sensitivity analyses. For example, before the sensitivity analysis the macadam pavement ranked first against murram for unpaved roads, and for paved roads the pavement with the triple seal surfacing was ranked ahead of that with the double seal surfacing. This order remained unchanged even after the sensitivity analyses.

The relative costs of the alternative project options for Kenyan roads are very small. For example, with variations in discount rate see table 6.4, the cost differences of unpaved roads range from 0.03 to 0.07 per cent, decreasing as the discount rate increases. For paved roads the cost differences fell within 0.11 and 0.23 per cent inclusive, increasing as the discount rate increases.

However, it is interesting to note that by changing the design life of the types of road project, their relative costs decrease as the their design life increases thus becoming constant after their designated design periods. Such results are useful in predicting the best design period for analysis. For example, for unpaved roads as the design periods varied the relative costs ranged from 0.11 to 0.06 per cent inclusive becoming constant on the 0.06 per cent and for paved roads ranged from 0.24% to 0.17% becoming constant on the 0.17% of the lowest cost from the options available with a given parameter.

With regard to changes in fuel costs, the relative costs of the alternative road types were unaffected. During the analysis conducted in this study, it was found that TLCC was by far more sensitive to discount rate and design life than to increases in fuel costs. The affect of discount rates on TLCC, indicated in percentages, range from 2 to 50 per cent for the Kenyan road types investigated. However, the effect of fuel cost is significantly low, ranging only from 0.5 to 3 per cent for all the Kenyan road types analysed.

6.8 SUMMARY AND CONCLUSION

6.8.1 Summary

Of the two road cases that were considered for analysis, one was a study of roads in a developing nation whereas the other studied roads in a developed nation. The analyses were conducted with the use of a Spreadsheet microsoft VP-Planner package. The analyses in both cases were based on the typical roads of the individual countries. Kenyan and New Zealand roads were considered in the analyses. By using the spreadsheet, it was necessary to identify all the data required for each road type. This required a knowledge of road design and construction standards, road maintenance policy, vehicle characteristics, flow and growth as well as road deterioration.

The package that was used facilitated calculation of the three major costs, viz. road construction, road maintenance and road vehicle operating costs. With this package it was possible to form inter-relationships between these costs and finally arrive at the total life cycle cost of the road project.

With this package it was possible to study different aspects of a road investment project, such as the best choice between a gravel, macadam, flexible or rigid pavement, the choice between labour-intensive and capital-intensive methods of construction.

The method that was adopted throughout the analyses was a capital-intensive method of working out the TLCC. The spreadsheet facilitated the study of the consequences of uncertainties in the discount rate, design period or fuel cost increase. The results of the total life cycle cost calculations were subjected to a sensitivity analysis with respect to those estimates or assumptions felt to be most uncertain.

6.8.2 CONCLUSION

1. The final decision resulting from the sensitivity analysis remains a matter of subjective judgement. However the decision-maker now has more solid information on which to base that judgement, and can readily identify the consequences of his decision.

2. According to the results from the analysis in this study, macadam pavement is the best option of the two alternatives considered under unsealed roads, whereas for sealed roads the pavement with triple seal surfacing is best for roads in Kenya.

   For New Zealand roads with a design period of 20 years, it is clearly shown that the flexible pavement type, alternative B with AP 40 and silty sand sub-base, proved the best option of the two alternatives investigated using all the discount rates and the other parameters in the analyses. The results from the analysis for rigid pavements show that reinforced concrete pavement, alternative C, is a better choice than the plain concrete pavement, alternative D.

3. It is found that Total Life Cycle Cost is generally sensitive to changes in discount rate and design life and not much affected by a variation in fuel cost increase. The effects of sensitivity of TLCC to discount rate and design life in this study ranges from 5 to approximately 60 per cent. The effects due to changes in fuel costs to the TLCC range from as low as 0.4 to 3 per cent.

4. From this study it is apparent that rigid pavements are by far the best option to run compared with flexible pavements. The reason being that there is only a little less maintenance required for rigid pavements than for flexible pavements.

CHAPTER SEVEN

DISCUSSION OF RESULTS

7.1 THE BRIDGE PROJECT

7.1.1 General

Having determined the total life cycle costs of alternative bridge types, it was sufficient to stop here and decide on the best option from the alternatives of the analysis. However, sensitivity analysis of TLCC to changes in discount rate, design life, materials and labour were conducted. Using 10% discount rate and a 60 year design period, the results of the analysis show the bridge types listed below in an order of importance with the lowest cost ranking first. Ranking of alternative bridge types before sensitivity analysis:

1. Concrete I-beam bridge
2. Timber bridge
3. Steel bridge
4. Concrete U-beam bridge

7.1.2 Discount Rate

The results of the sensitivity analysis of TLCC to the discount rates given in tables 5.2 and 5.3 did not change the order of ranking shown above. However, the effects are remarkable within each bridge type as the discount rate reduces from 10% to 0%. For example, the TLCC of the concrete U-beam bridge increases from 18% to 101%, and for a concrete I-beam it ranges from 25% to 36%, while for the steel and timber bridge types this ranges from 26% to 150% of the costs of each alternative project type with a 10% discount rate. However, increasing the discount rate from 10% to 20% decreases the TLCC of the bridge types ranging from 8% to 13%. It should be noted here that the higher the discount rate the higher the risk and uncertainty associated with the project. However, discount rates, for example, higher than 20% are likely to give false results and therefore should not be used.

It important to note the relative difference in costs for alternative bridge types as the discount rate varies. Taking the least cost as a reference value of the alternatives for a given parameter, the relative cost percentage difference for the results in table 5.2 are 17 and 22 per cent for a 0% discount rate. For the other discount rates the relative costs of the bridge types are 1% and 5% from the least cost value. However, the results from table 5.3 show constant percentage cost differences of 32% and 33% throughout as the discount rate varies from 0% to 20%. The constant variation in the relative costs as the discount rate changes is due to identical maintenance operations carried out on the bridge types during the given design period with the exception of the result in table 5.2 with a 0% discount rate.

7.1.3 Design Period

Total life cycle costs of alternative bridge types are less sensitive to design period than to discount rate. For instance, varying the design period from 60 to 20 years reduces the TLCC of bridge types and their values range from 0% to 6.5%, see table 5.4. However, increasing the design life of the bridge types increases their TLCC to 0.1% of costs of each alternative project option with 60 years design period throughout. This shows a 60 year design life as an optimum value for analysing bridges, since beyond this value there is virtually no effect of TLCC to changes in design life.

Varying the design life may also alter the relative costs of the bridge types. Using the least cost as a reference value, it was noticed that for 20 and 30 year design periods the cost percentage differences for the alternative options were 1% and 4% of the least cost from the available options for a given parameter. From 40 to 100 year design periods the cost differences were close to 0% and 2% throughout. Such small figures may be due to discounting as discounting factors reduce in value as the design period increases.

7.1.4 Material and Labour Cost Increases

The results from the analysis in table 5.5 show that TLCC is less sensitive to increase in material and labour costs than to discount rate. Increasing the costs of material and labour by 20%, the TLCC increases and their values lie within a range of 1% and 7% of the cost of each alternative project with 60 years design life discounted at 10%. For example, when the cost of steel material was increased by 20% the the TLCC of concrete, steel and timber were increased by about 4%, 6% and 1% respectively.

Increasing the labour costs to 20% increased the TLCC of the bridge types by about 3%. It is interesting to note a small increase in the TLCC as the labour costs increase. The reason for this is that most of the work is carried out with plant and equipment with only a small proportion carried out by labour.

The relative costs of the bridge types, in this regard, range from 1% to 6% of the least cost from alternative project options for a given parameter as costs are increased to 20%.

7.1.5 Implications of Results

From the results of the analysis it is clear that evaluation of a project with the use of total life cycle costing technique facilitates exploration of all possibilities on a project before a decision is made. Total life cycle costing provides a facility for assessing the impact of a change in a single parameter value within a project by applying the sensitivity analysis approach. The sensitivity analysis approach helps remove the uncertainty inherent in total life cycle costs and also serves as a means of comparing alternative project options. From the four alternative bridge types considered concrete I-beam was the best option as it had the lowest total life cycle cost. The results also showed that total life cycle cost was significantly more sensitive to discount rate than to design period, material and labour costs. Therefore the use of sensitivity analysis to the total life cycle costing technique is necessary for comparing alternative options.

7.2 NEW ZEALAND ROAD PROJECT

7.2.1 General

The reason for considering a number of varying projects in this study is to find out the suitability of total life cycle costing technique with regard to various projects in the construction industry.

For New Zealand roads a 10% discount rate was used as the basis of analysis. Flexible and rigid pavements with design lives of 20 and 40 years respectively were analysed. The total life cycle costs of these project types were determined and later a sensitivity analysis of these values was carried out. The road types, with their alternative options, ranked in their order of importance before sensitivity analysis was carried out are given below.

New Zealand Road project ranking before sensitivity analysis:

(a) Flexible Pavement

1. Flexible pavement (alternative B) with AP 60 sub-base.

2. Flexible pavement (alternative A) with AP 40 and silty sand sub-bases.

(b) Rigid Pavement

1. Rigid pavement with reinforced concrete surfacing (alternative C)

2. Rigid pavement with plain concrete surfacing (alternative D)

The results of sensitivity analyses of total life cycle costs to discount rate, design period and fuel cost increase for New Zealand roads are discussed below.

7.2.2 Discount Rate

The results from table 6.1 show that after sensitivity analysis the ranking of flexible pavement road types remains unchanged whereas for the rigid pavements the order changes from alternative C to D as the discount rate increases from 10% to 20%.

The results of the analysis show that total life cycle costing is sensitive to discount rate. For instance, it is observed that by changing the discount rate from 10% to 20% reduces the TLCC of these road types from a range of 0% to 56%. This shows how TLCC is significantly sensitive to discount rate. It is interesting to note from the results of the analysis in table 6.1 that there were no sizeable differences in the relative costs of the alternative road types. For example, the difference in costs from flexible pavement alternative options ranged from 0.003% to 0.05% whereas for rigid pavement alternative options this ranged from nearly 0% to 0.15%. Such small differences, as in flexible pavements, is an indication of the similar nature of works carried out on these alternative options. The slight increase in cost for rigid pavements is due to the difference in the initial costs as well as the frequency of maintenance.

7.2.3 Design Period

The results from table 6.2 show that LCC is largely sensitive to changes in design life. For example, decreasing the design life of flexible pavement from 20 to 10 years decreased the TLCC within a range of 0% to 41%. The effect of a change in the design period for rigid pavements as the service life was decreased from 40 to 10 years ranged from 0% to 56%. Such a significant change in TLCC are attributable to maintenance work which occurs at various intervals during the study period of roads. This is really important as one can decide on the optimum year in which a project will be most cost effective.

As the design period varies so does the relative costs of the alternative options. The differences in costs for both flexible and rigid pavements ranged from 0.003% to 0.04%. This is due to the fact that vehicle operation costs contribute a sizeable proportion of the total cost.

Having carried out a sensitivity analysis of TLCC to design period, the order of ranking the alternative road type options was revised. Below is the ranking according to order of importance after the sensitivity analysis:

(a) Flexible Pavement: (no change in ranking order after sensitivity analysis)

(b) Rigid Pavement:

(i) With 10 years design period:
1. Alternative D
2. Alternative C

(ii) With 15 years design period:
1. Alternative D
2. Alternative C

(iii) With 20 years design period:
1. Alternative C
2. Alternative D

(iv) With 25 years design period:
   1. Alternative C
   2. Alternative D

(v) With 30 years design period:
   1. Alternative C
   2. Alternative D

7.2.4 Fuel Cost Increase

Analysis from table 6.3 show that TLCC is less sensitive to fuel cost increase. Increasing current the fuel cost from 0% to 15% only showed a slight increase in the TLCC as it varied from 0% to 1.2%. Although this figure looks small it is of significant importance in the economic evaluation of projects.

7.2.5 Implications of Results

It is evident that total life cycle cost technique is suitably applicable in the economic evaluation of roads, especially, if sensitivity analysis approach is incorporated in it. With respect to roads, the TLCC is significantly sensitive to discount rate and design period and less sensitive to fuel cost increase. The total life cycle costing technique stands well above all other methods of economic evaluation in assessing projects with durable assets. From the results of the analysis the best road option turns out to be alternative B for flexible pavements. For rigid pavements it is alternative C with reinforced concrete surfacing which is the best option to run with a 10% discount rate through most of its design life. However, for discount rates greater than 10% alternative (D) turns out to be the better option of the two. When looking at long term running of a project a rigid pavement is far more economical than a flexible pavement according to the results of the analyses for roads in New Zealand. The reason being that it needs little period maintenance work carried out during its service life. However, for a short term project, with future developments planned, a flexible pavement is preferable.

7.3 KENYAN ROAD PROJECT

7.3.1 General

During this study it was found necessary to consider the application of total life cycle costing in at least one of the developing nations. Kenya was chosen as an example for countries with limited management skills, especially in Africa. There is need in such countries to manage projects effectively after they have been constructed. The total life cycle technique, in this regard, serves as an answer to this problem as it deals with the future running costs of a project.

A road project was taken as one of the major great needs which requires efficient project management. Paved and unpaved roads were considered for analysis and their total life cycle costs were determined. Sensitivity analysis of TLCC to discount rates, design life and fuel cost increases were carried out to assess their effects on the whole cycle costs of the alternative road types.

Basing the analysis on a 15% discount rate and 20 year design life, the following results were obtained. These results give the TLCC of paved and unpaved road surfaces before the sensitivity analysis.

Kenyan road project ranking before sensitivity analysis:

(a) Unpaved Road:

1. Macadam pavement
2. Murram pavement

(b) Paved Road:

1. Triple seal surfacing pavement
2. Double seal surfacing pavement

The results of the analysis after sensitivity analysis are discussed in the following sections.

7.3.2 Discount Rate

The results of the analysis in table 6.4 show that TLCC is significantly sensitive to discount rate. The results show that reducing the discount rate from 15% to 10% increases the TLCC with its value ranging from 0%

to 46% for both paved and unpaved roads. The TLCC increases as a result of the increase in the discount rate factor which increases as its discount rate decreases and vice versa.

After the sensitivity analysis, the order of ranking remained unaltered for both paved and unpaved roads. From the results of the analysis it shows that changing the discount rate has got little to do with the order of ranking of projects apart from a few exceptions such as the rigid pavement for the New Zealand road project.

7.3.3 Design Period

The order of ranking the projects remained unaltered as the design period varied see table 6.5. However, TLCC was affected as result of a change in the design period. Reducing its design period from 20 to 10 years reduced the TLCC from 0% to 29%. This is again attributed to the fact that different maintenance works are carried out at different intervals depending on the deterioration rate of the road. There is little change in TLCC as the design period increases from 20 to 25%. The change in TLCC ranges from 0% to 2% as the design period increases by this amount. This shows that a 20 years design period is an optimum value for analysing these types of roads. For design periods greater than 20 years the results of the analysis will give misleading output.

7.3.4 Fuel Cost Increase

While mindful that there might be shortages of fuel in the future and as a result costs are likely to escalate, it is therefore important to assess the effect of an increase in the cost of fuel to the TLCC. The results from table 6.6 show that an increase in fuel costs has less effect on the TLCC when compared with the discount and design period. However, it was observed that as the fuel cost was increased from its current price to 15%, TLCC increased by about 3% for unpaved roads and about 1.5% for paved roads. Fuel consumption on unpaved roads is twice as much as that on paved roads according to this study.

Another interesting thing to note here is that the project ranking prior to carrying out a sensitivity analysis remained unaltered similar to the results obtained from the New Zealand project.

7.3.5 Implication of Results

The results from the analysis show that for unpaved Kenyan roads Macadam pavement is a better option than the gravel road type. It is always better to spend a sizeable initial amount in order to be able to save in the future. This is demonstrated by the results of unpaved roads in which the capital cost of macadam pavement are higher than those of a gravel pavement. However, the running costs of the gravel road makes it uneconomical in the long run. For Kenya, paved roads with triple seal surfacing, is the preferred pavement as it has a lower total cost than the double seal surfacing pavement.

The sensitivity analysis results on Kenyan roads confirm what has already been learned from the analysis of New Zealand roads; that total life cycle is sensitive to discount rate and design period but less sensitive to increase in fuel cost.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

8.1 CONCLUSIONS

This work has shown that the total life cycle costing technique is an appropriate economic evaluation method which can effectively incorporate initial and future costs into its economic analysis. This study has also shown that total life cycle costing is applicable to various work in the construction industry.

Chapter 3 of this work presented an evaluation framework for carrying out the total life cycle costing technique. On the basis of this framework it is necessary to use a simple and practical method for performing the analysis. A VP-Planner worksheet was adopted (chapter 4). The projects that were analysed with this new method of economic evaluation were bridge and road projects. The results of the analyses are presented in Chapters 5 & 6 and the details in the Appendices.

The following conclusions are drawn:

1. Total life cycle costing can be applied to all construction works in the construction industry. This study has covered bridges and roads, however, analyses of other projects such as irrigation schemes, earth dams, sports complexes, etc, can also be carried out using the total life cycle costing technique.

2. Total life cycle costing and sensitivity analysis facilitate effective choice given a number of alternative project options and serve as a means of achieving a cost effective project option. LCC and sensitivity analysis, incorporated together can dramatically improve the quality of decisions. Therefore, total life cycle cost with sensitivity analysis approach incorporated in it serves well as a decision-making tool.

3. Although there are several methods of investment appraisal, only one is properly applicable to total life cycle costing, and that is net present value.

4. The results of the analyses from the projects conducted in this study show that total life costing is more sensitive to discount rate and design life than to fuel cost increase, material and labour costs.

5. The concrete I-beam bridge was the best option from the alternative bridge types that were analysed by using total life cycle costing technique and sensitivity analysis approach.

6. For the Kenyan road project, macadam pavement was the best option for unpaved roads and for paved roads triple seal surfacing proved the best option. For New Zealand roads, flexible pavement (alternative B) with AP 60 sub-base was the best option and for rigid pavements the one with reinforced concrete surfacing became the best option. Choice was based on the projects with the lowest total cost after the sensitivity analysis.

8.2 RECOMMENDATIONS FOR FURTHER STUDY

1. Total life cycle costing requires knowledge of the performance of the project's components in order to establish with confidence the life of a project. It is therefore necessary to know the performance of the individual components in order to facilitate future planning.

2. For total life cycle to be fully applicable in the construction industry it is important to set up an acceptable means of recording data and building up a database. This data base will then be used for future planning.

3. The analyses of total life cycle cost in this study was based on an economic life, i.e., the least cost alternative which met a desired option. A study could be made by basing it on the anticipated physical life, i.e., when the project is completely worn out.

4. All the analyses in this study were performed on the assumption of stable economic conditions throughout the study period. Further work is needed to study the importance of including inflation in the analysis of total life cycle cost.

REFERENCES

1. BROWNE, R. Durability of reinforced concrete structures, New Zealand Concrete Construction, Vol. 33, Sept. 1989.

2. CONSTRUCTION MANAGEMENT & ECONOMICS, Vol. 5, 1987, E & F.N. Spon Ltd.

3. DARREL D.N. Wood Deterioration and Its Prevention by Preservative Treatments, Syracuse University Press, USA, 1973.

4. DAVID, A. DAY, P.E., Construction Equipment Guide, John Wiley & Sons Inc.,1973.

5. DE VEEN, J.J., The Rural Access Roads Programme - Appropriate Technology in Kenya. International Labour Organisation, 1980.

6. FLANAGAN, R., NORMAN, G., Life Cycle Costing for Construction, Royal Institution of chartered Surveyors (Quantity Division), July 1983.

7. HENRI, L.B., CARAPETIS, S., CROWTHER, L., HERTEL, S. Rural Transport Services - A guide to their Planning and Implementations, Intermediate technology publications 1987.

8. HODGES, J. W., ROLT, J. and JONES, T. E., The Kenya Transport of Environment, TRRL Report LR 673. Crowthorne, 1975 (Transport and Road Research Laboratory).

9. KEITH, C., Fundamentals of Construction Estimating and Cost Accounting, Prentice-Hall, Inc., U S A, 1974

10. KENNETH, R.W., MINOR, J., KENNETH, N.D., CONRAD, P.H., Bridge Maintenance, Inspection and Evaluation, Marcel Dekker, Inc., USA, 1981.

11. KILBOURN, P.C.R., and ABELL, R., Transport and Road Research Laboratory, U.K. Whole Life Costs of Concrete Pavements. PTRC Education and Research Services LTD 1988.

12. LIFE CYCLE COSTS FOR ARCHITECTS - A draft design manual, Joint Centre for Land Development Studies, University of Reading, College of Estate Management.

13. Mc CLEARY, W.A., MOISE, A., BERTIL NILSSON, Equipment Versus Employment, International Labour Organisation, 1976.

14. MEYER, R.W., KELLOGG, R.M., Structural uses of wood in adverse Environments, Van Nostrand Reinhold, USA, 1982.

15. NUNALLY, S.W., Managing Construction Equipment, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA. 1977.

16. ODIER, L., MILLARD, R.S., PIMENTEL DOS SANTOS, MEHRA, S. R., Low Cost Roads - Design, Construction and Maintenance, UNESCO 1971, Butterworths, U.K.

17. RAWLINSONS, New Zealand Construction Handbook, Rawlinsons & Co., N.Z., 1989.

18. ROBINSON, R., HIDE, H., HODGES, J. W., ROLT, J. AND ABAYNAYAKA, S.W., A road transport investment model for developing countries. Department of the Environment, TRRL Report LR 674. Crowthorne 1975 (Transport and Road Laboratory)

19. ROSALIE, T.R., Life Cycle Costing Manual for Federal Energy Management Programme, Government Printing, USA, 1987.

20. SALTER, R.J., Highway Design and Construction. Macmillan Education, U.K., 1988.

21. SOMERVILLE, G., 'The Design Life of Concrete Structures', The Structural Engineer, 64A, No.2 February 1986.

22. STONE, P.A., Building Design Evaluation: Cost-in-use, 1967, E. & F. Spon Ltd.

23. THAWAT WATANATADA et al, Highway Design and Maintenance Standards Study, Vol.IV, HDM II Model Description and User's Manual with Highway Expenditure Budgeting, World Bank, 1984 (Draft).

24. TIETZ, S.B., Life Cycle Costing and Whole Life Design, The Structural Engineer, 65A, No.1, January 1987, pp 10-11.

APPENDIX A

DETAILS OF INPUT AND OUTPUT FOR THE BRIDGE PROJECT

Table: A 1 COST DATA

	Description	Units	Cost
1	Unskilled labourer	hr	$14
2	Skilled labourer	hr	$17
3	Excavator	hr	$40
4	Formwork	sq.m	$75
5	Formwork (Ply)	sq.m	$30
6	Dumper	hr	$85
7	Reinforcing steel	ton	$1,265
8	Prestressing steel	ton	$8,000
9	Ready-mix concr. Mpa25	cu.m	$151
10	Ready-mix concr. Mpa30	cu.m	$156
11	Str.steel erector	hr	$43
12	Truck	hr	$18
13	Mobile crane	hr	$120
14	Roller (8 ton)	hr	$40
15	Concr. mixer 0.2/0.14	day	$40
16	Overheads	%-ge	10%
17	Bituminous concrete	sq.m	$35
18	Glulam beam	cu.m	$1,700
19	Deck plank	m	$12
20	Wire nails	kg	$3
21	Elastometric bearing	no.	$260
22	Built-up sections	ton	$2,250
23	Guardrail(labour included)	m	$245
24	" for timber bridge	m	$130
25	Casing (detailed price)	m	$500
26	Blinding concrete	sq.m	$12
27	stud connectors	no.	$9
28	Pumping concrete	cu.m	$25
29	Concrete truck	hr	$50
30	250x200 timber block	m	$52
31	250x100 timber block	m	$26
32	M24x640 bolts	no.	$30
33	Grader	hr	$60
34	Concrete I-beams	no.	$6,200

Table A 2: Construction Cost Estimates for the Bridge Project

Description	Units	Performance mam-hr/unit S.L	Performance mam-hr/unit U.L	Labour cost $	Plant cost $	Mat-l cost $	O/H 10%	Total Unit Cost
1	2	3		4	5	6	7	8
1 CONCRETE								
Abutments	cu.m		2	32	41	151	22	245
Deck & Cross beams	cu.m		2	32	41	156	23	251
U-beams	cu.m		3	42	41	156	24	262
Piles	cu.m		3	41	41	151	23	255
2 REINFORCING STEEL								
Abutments	tonne	25		425	60	1265	175	1925
Deck & Cross beam	tonne	25		425	60	1265	175	1925
U-beam (bars)	tonne	25		425	60	1265	175	1925
U-beam (prestressing)	tonne							
Piles	tonne	25		425	60	1265	175	1925

1	2	3	4	5	6	7	8
3 FORMWORK							
Abutments	sq.m	1	23		30	5	58
Deck & cross beam	sq.m	2	40		30	7	77
U-beam	sq.m	3	47		30	8	85
4 STRUCTURAL STEEL WORK							
Built up beams	tonne	45	765	175	2250	319	3509
5 TIMBER							
Glulam beam (1700x280)	m						809
Diaphragm (1500x280)	m						714
Deck	m						
6 SEALING							
Asphalt seal	sq.m						35

Table A 3: Concrete Bridge Schedule of Quantities & Rates

	Description	Units	Quant	Rates	Amount
1	Establishment	l.s			5000
2	Pile casings	m	20.0	500	10000
3	pile reinforcement	ton	2.6	1925	4928
4	Concrete in piles	cu.m	13.5	255	3449
5	Abut & s/slab blinding conc.	sq.m	16.0	12	192
6	Formwork in abutment	sq.m	45.0	58	2621
7	Abut. reinforcement	ton	1.6	1925	3080
8	Concrete in abutment	cu.m	10.0	245	2454
9	Bearings	no	8.0	260	2080
10	Formwork in U-beams	sq.m	200.0	85	16922
11	Concrete in U- Beams	cu.m	32.0	262	8400
12	Prestressing reinforcement	ton	2.5	8000	20000
9	Reinforcement in U-beams	ton	1.2	1925	2310
14	Formwork in Deck	sq.m	120.0	77	9233
15	Deck & Cross beam reinf-t	ton	2.7	1925	5198
16	Deck & Cross beam concrete	cu.m	30.0	251	7528
17	Asphalt seal	sq.m	130.0	35	4550
18	Guardrail	m	50.0	245	12250
			Capital cost=		$120,195

Table A 4: Steel Bridge Schedule of Quantities & Rates

	Description	Units	Quant	Rates	Amount
1	Establishment	l.s			5000
2	Pile casings	m	20.00	500	10000
3	pile reinforcement	ton	2.56	1925	4928
4	Concrete in piles	cu.m	13.50	255	3449
5	Abut & s/slab blinding conc.	sq.m	16.00	12	192
6	Formwork in abutment	sq.m	45.00	58	2621
7	Abut. reinforcement	ton	1.60	1925	3080
8	Concrete in abutment	cu.m	10.00	245	2454
9	Concrete stud connector	no	184.00	9	1564
10	Builtup steel beam & bracing	ton	12.00	3509	42102
11	Deck slab concrete	cu.m	28.00	77	2154
12	Deck slab reinforcement	ton	2.50	1925	4813
13	Formwork in Deck	sq.m	120.00	77	9233
14	Asphalt seal	sq.m	130.00	35	4550
15	Guardrail	m	50.00	245	12250
			Capital cost=		$108,390

Table A 5: Timber Bridge Schedule of Quantities & Rates

	Description	Units	Quantity	Rates	Amount
1	Establishment	l.s			5000
2	Pile casings	m	20.00	500	10000
3	pile reinforcement	ton	2.56	1925	4928
4	Concrete in piles	cu.m	13.50	255	3449
5	Abut. blinding concrete	sq.m	16.00	12	192
6	Formwork in abutment	sq.m	45.00	58	2621
7	Abut. reinforcement	ton	1.60	1925	3080
8	Concrete in abutment	cu.m	10.00	245	2454
9	Diaphragms	m	5.00	714	3570
10	1700x280-Glulam beam	m	50.00	809	40460
11	Deck slab concrete	cu.m	28.00	77	2154
12	Deck slab reinforcement	ton	2.50	1925	4813
13	stud connectors	l.s			1500
14	Formwork in Deck	sq.m	120.00	77	9233
15	Asphalt seal	sq.m	130.00	35	4550
16	Guardrail	m	50.00	245	12250
			Capital cost=		$110,254

Table A 6: Operating Cost Estimates for New Zealand Bridge Project

Descriptions	Units	Qty	Hours per year	Labour costs	Tools Cost 4%x Labcost	Unit rates
1 PATROL CREW Inspection once every 6 months one crew required for 1.5 hours Transportation cost say $50	no.	1	3	22	3	69
2 DIRT & DEBRIS REMOVAL Maint-ce crews (2 men) Removal once a year for 3hrs Cost of tools say 4% of labour cost	sq.m	130	3	20	5	.96
3 PATCHING Once every 2 years for 18 hrs repair covers 10% of surface area. Maint-ce crew (no.2)	sq.m	13	9	22	16	31.68
4 BREAKOUT & REPAIR REBARS Rate of breakout to a depth of 25mm behind rebar is 0.4sq.m per day per worker Labour: ($20/hr)x 8 =$160 Tool: 4% of labour cost =$6.40 Material cost =$15 Total cost = $181.40 Rate = $453.50/sq.m		sq.m	216		20	

Table A 7: Concrete Bridge schedule of rates & Maintenance Costs (Annual)

DESCRIPTIONS	Unit	Quantity	Unit Rates	Cost/yr
1 Patrol crews	no.	1	69	69
2 Dirt & Debris removal	sq.m	130	.96	125
3 Snow & Ice removal	sq.m			0
4 Patching	sq.m	12	31.68	380
5 Traffic damage (eg. guardrail)	m	5	245	1225

Total maintenance costs = $1,799

Present value (60yrs) = $17,927
Discount rate = 10%

Table A 8: Steel Bridge Schedule of Rates & Maintenance Costs (Annual)

DESCRIPTIONS	Unit	Quantity	Unit Rates	Cost/yr
1 Patrol crews	no.	1	69	69
2 Dirt & Debris removal	sq.m	130	.96	125
3 Snow & Ice removal	sq.m			0
4 Patching	sq.m	12	31.68	380
5 Traffic damage (eg. guardrail)	m	5	245	1225

Total maictenance costs = $1,799

Present value (60yrs) = $17,927
Discount rate = 10

Table A 9: Timber Bridge Schedule of Rates & Maintenance Costs (Annual)

DESCRIPTIONS	Unit	Quantity	Unit Rates	Cost/yr
1 Patrol crews	no.	1	69	69
2 Dirt & Debris removal	sq.m	130	.96	125
4 Snow & Ice removal	sq.m			0
5 Patching	sq.m	12	31.68	380
7 Traffic damage (eg. guardrail)	m	5	245	1225
	Total maintenance costs =			$1,799
	Present value (60yrs) =			$17,927
	Discount rate = 10%			

Table A 10: Concrete Bridge Refurbishment/Replacement Costs, Discounted at 10% with a Design Life of 60 years

Descriptions	Units	QTY	Refurb. costs	Interval (years)	Proportion to be refurb. or replaced	Cost	PVF	PV
1 DECK REPAIR								
Overlaying (asphalt 25mm thick)	sq.m	130	35	20	100%	4550	.171	777
2 GIRDER STRENGTHENING								
Breakout 25 mm depth behind bars and repair	l.s			30		20000	.057	1146
3 DEAD LOAD REDUCTION								
Remove excess (asphalt) overlay Time spent by grader 3 hours	l.s			20	100%	2000	.171	341
4 GEOMETRY (now 2 lanes 8.6m wide) Roadway widening(4.3m wide extra) Substructure extension(abut&pile) New Girders & bearings	l.s			30	100%	120195	.057	6888
5 MECHANICAL DEFICIENCIES Refurbish bearings Replace Joint Seal	l.s			30	100%	20000	.057	1146
6 SAFETY & SERVICEABILITY								
Adjust roadway alignment	l.s			5	100%	500	1.629	815
7 PAINTING & CLEANING	l.s			10	100%	15000	.622	0

Total Present value (TPV) = $11,114

Table A 11: Steel Bridge Refurbishement/Replacement Costs, Discounted at 10% with a Design Life of 60 years

Descriptions	Units	QTY	Refurb. costs	Interval Years	Proportion refurbished or replaced	Cost	Present Value Factor	Present Value
1 DECK REPAIR								
Overlaying (asphalt 25mm thick)	sq.m	130	35	20	100%	4550	.171	777
2 GIRDER STRENGTHENING	l.s			30	100%	20000	.057	1146
3 DEAD LOAD REDUCTION								
Remove excess (asphalt) overlay				20	100%	2000	.171	341
Time spent by grader 3 hours								
4 GEOMETRY (now 2 lanes 8.6m wide)	l.s			30	100%	108390	.057	6212
Roadway widening(4.3m wide extra)								
Substructure extension(abut&pile)								
New Girders & bearings								
5 MECHANICAL DEFICIENCIES	l.s			30	100%	20000	.057	1146
Refurbish bearings								
Replace Joint Seal								
6 SAFETY & SERVICEABILITY								
Replace bridge guardrailing	l.s			5	100%	500	1.629	815
Adjust roadway alignment								
7 PAINTING & CLEANING	l.s			10	100%	15000	.622	9332

Total Present value (TPV) = $19,769

Table A 12: Timber Bridge Refurbishment/Replacement Costs, Discounted at 10 % with a Design Life of 60 years

Descriptions	Units	QTY	Refurb. costs	Interval years	Proportion refurbished or replaced	Interval Cost	Present value factor	Present value
1 DECK REPAIR								
Overlaying (asphalt 25mm thick)	sq.m	130	35	20	100%	4550	.171	777
2 GIRDER STRENGTHENING	l.s			30	100%	20000	.057	1146
3 DEAD LOAD REDUCTION								
Remove excess (asphalt) overlay				20	100%	2000	.171	341
Time spent by grader 3 hours								
4 GEOMETRY (now 2 lanes 8.6m wide)	l.s			30	100%	110254	.057	6318
Roadway widening(4.3m wide extra)								
Substructure extension(abut&pile)								
New Girders & bearings								
5 MECHANICAL DEFICIENCIES	l.s			30	100%	20000	.057	1146
Refurbish bearings								
Replace Joint Seal								
6 SAFETY & SERVICEABILITY								
Replace bridge guardrailing	l.s			5	100%	500	1.629	815
Adjust roadway alignment								
7 CLEANING & PAINTING	l.s			10	100%	12000	.622	7465

Total Present value (TPV) = $18,009

APPENDIX B

This appendix shows the data used in analysing the New Zealand road project. A clear outline of how some of these results are achieved is given in Appendix B as an illustration esepcially for vehicle operating costs. In addition, the information in the following tables gives the input and output data of the New Zealand road project.

Table B 1: List of the Cost Data Estimates for New Zealand Road Project

Item	Descriptions	Unit	Unit Costs ($/unit)
1	NRB M/4 Basecourse	cu.m	$4.00
2	AP40 Run of Crusher	cu.m	$2.65
3	AP60 Crushed Stone	cu.m	$1.85
4	Silty Sand	cu.m	$7.15
5	Ready mixed concerete 20 MPa	cu.m	$144.00
6	Ready mixed concrete 30 MPa	cu.m	$156.00
7	Mesh reinforcement (664) 6 mm dia.	sq.m	$9.50
8	Ready mixed chap seal (25 mm thick)	sq.m	$8.00
9	Tipper truck (4 cm.m)	hr	$15.00
10	8 ton Wheeled Roller (110 hp)	hr	$50.00
11	Concrete finisher (200 hp)	hr	$150.00
12	Mortered grader (91 hp)	hr	$100.00
13	Diesel fuel	litre	$.60
14	Petrol	litre	$.93
15	Engine oil	litre	$5.65
16	Bulldozer 100 hp	hr	$100.00
17	Concrete vibrator (75 mm dia.) 40 hp	hr	$5.00
18	Concrete saw-diesel 14" (40)	hr	$6.88
19	Compressor (600 CFM) 40 hp	hr	$95.00
20	Transit mixer truck (6 cu m), 100 hp	hr	$25.00
21	Skilled labour	hr	$22.00
22	Unskilled labour	hr	$18.00
23	Water truck	hr	$10.00
24	Sealing chips	cu.m	$8.57
25	Double seal surfacing (5000 sq.m)	sq.m	$7.00

PAVEMENT DESIGN

An economic analysis of flexible and rigid pavements is carried out in order to arrive at the best alternative of the two.

1. Flexible Pavement

Two lane two-way highway carrying 1205 vehicles/day, of which 18% are heavy commercial vehicles (for which average load factor is 0.5 EDA/HCV) during 300 days/year, is considered for analysis. The highway is classified as a lower grade facility and is not based on any particular road. However, the analysis is based on New Zealand National Road Board's Standards.

Data

Heavy commercial vehicles	21%
Average load factor	1
Vehicles/day	1205
Design period	20 years
50-50 split in each direction is assumed	
Vehicle growth rate	3%
Present annual traffic loading (A)	18979 EDA/year
Total design loading (T)	517578 EDA/lane

Materials

1. M/4 Basecourse
2. AP 40 aggregate (CBR = 60, SE = 50)
3. AP 60 aggregate (CBR = 40, Se = 45)
4. AP 50 aggregate (CBR = 20, SE = 20)
5. Silty sand (CBR = 20, Se = 18)

NOTE: SE = Sand Equivalent
AP = All passing; the topsizes for materials 2, 3 and 4 are 40, 60 and 50 mm respectively
CBR = California Bearing Ratio

The ratio of topsize to layer thickness must not exceed 0.45.
The design sub-grade CBR is assumed to be 8.

Table B 3.2: Design Detail of the Rigid Pavement Alternative (D) for New Zealand Road Project

Layer	Material	Thickness
SURFACING	Asph. concr.	170 mm
BASE	M/4	105 mm
SUB-BASE	AP 60	170 mm

Table B 2.1: Design Detail of the Flexible Pavement Alternative (A) for New Zealand Road Project.

Layer	Material	Thickness
SURFACING	Chip seal	25 mm
BASE	M/4	140 mm
SUB-BASE		
Upper subbase	AP 40	90 mm
Lower subbase	Silty sand	55 mm

Table B 2.2: Design Detail of the Flexible Pavement Alternative (B) for New Zealand Road Project.

Layer	Material	Thickness
SURFACING	Chip seal	25 mm
BASE	M/4	140 mm
SUB-BASE	AP 60	145 mm

Table B 3.1: Design Detail of the Rigid Pavement Alternative (C) for New Zealand Road Project.

Layer	Material	Thickness
SURFACING	Asph. concr.	160 mm
BASE	M/4	105 mm
SUB-BASE		
Upper subbaase	AP 40	100 mm
Lower subbase	Silty sand	70 mm

Table B 4: Table Used to Calculate Activities Time Estimates Together with their Labour Costs for New Zealand Road Project.

Description	Input	No.of Input	Units	Prod. (QTY/Unit)	Duration (Hrs)	Labour Cost ($/QTY)	Total ($/QTY)
1	2	3	4	5	6	7	8
EARTHWORK:	Bulldozer	1	hr	38	245		
(i) Top soil	Operator	1	hr		245	.57	
Quantity:	Worker	1	hr		245	.47	1.04
9400 cu.m							
(ii) Cut & Fill	Bulldozer	1	hr	33	394		
Quantity:	Wheel-roller	1	hr	122	394		
13000 cu.m	Foreman	1	hr		394	.67	
	Operator (Dozer)	1	hr		394	.67	
	Operator (Roller)	1	hr		394	.67	
	Worker	2	hr		394	1.09	3.09
(iii) Sub-grade finish	Bulldozer	1	hr	80	154		
Quantity:	Wheel-roller	1	hr	122	154		
12300 cu.m	Foreman	1	hr		154	.28	

1	2	3	4	5	6	7	8
	Operator (Dozer)	1	hr		154	.28	
	Operator (Roller)	1	hr		154	.28	
	Worker	2	hr		154	.45	1.28
METAL COURSE:							
(i) Upper sub-base	Tip. truck (4 cu.m)	3	hr	60	55		
(AP 40)	Water truck (6 cu.m)	1	hr		55		
Quantity:	Grader	1	hr	60	55		
3285 cu.m	Roller	1	hr	60	55		
	Drivers	4	hr		55	1.47	
	Foreman	1	hr		55	.37	
	Operators	2	hr		55	.73	
	Workers	2	hr		55	.60	3.17
(ii) Lower sub-base	Tip. truck (4 cu.m)	4	hr	110	18.3		
(Silty sand)	Water truck (6 cu.m)	1	hr		18.3		
Quantity:	Grader	1	hr	110	18.3		
2010 cu.m	Roller	1	hr	110	18.3		
	Drivers	5	hr		18.3	1.00	
	Foreman	1	hr		18.3	.20	
	Operators	2	hr		18.3	.40	
	Workers	2	hr		18.3	.33	1.93

1	2	3	4	5	6	7	8
(iii) Sub-base (AP 60)	Tip. truck (4 cu.m)	3	hr	60	88		
Quantity:	Water truck (6 cu.m)	1	hr	60	88		
5300 cu.m	Grader	1	hr	60	88		
	Roller	1	hr	60	88		
	Drivers	4	hr		88	1.47	
	Foreman	1	hr		88	.37	
	Operators	2	hr		88	.73	
	Workers	2	hr		88	.60	3.17
BASE COURSE:							
M/4 solid	Tip. truck (4 cu.m)	3	hr	60	85.2		
Quantity:	Water truck (6 cu.m)	1	hr	60	85.2		
5110 cu.m	Grader	1	hr	60	85.2		
	Roller	1	hr	60	85.2		
	Drivers	4	hr		85.2	1.47	
	Foreman	1	hr		85.2	.37	
	Operators	2	hr		85.2	.73	
	Workers	5	hr		85.2	1.50	4.07
SURFACING:							
(i) 25mm Double seal	Tip. truck (4 cu.m)	3	hr	44	21		
Quantity:	Grader	1	hr	44	21		
913 cu.m	Roller	1	hr	44	21		
	Drivers	3	hr		21	1.50	

1	2	3	4	5	6	7	8
	Foreman	1	hr		21	.50	
	Operators	2	hr		21	1.00	
	Workers	2	hr		21	.82	3.82
(ii) Concrete paving	Transit truck (6cu.m)	1	hr	15	414		
Quantity: (Plain concrete)	Concrete finisher	1	hr	15	414		
6210 cu.m	Concrete vibrator	2	hr	15	414		
	Concrete saws	2	hr	15	414		
	Compressor	1	hr	15	414		
	Foreman	1	hr		414	1.47	
	Driver	1	hr		414	1.47	
	Operator	1	hr		414	1.47	
	Workers	5	hr		414	6.00	10.40

Table B 5: Table for Calculating the Equipment Cost Estimates Including Attendant. for New Zealand Roads

Description	Units	Output (Unit/hr)	EQUIPMENT Fuel consumed (L/hr)	Usage time (hrs)	required time (hrs)	Fuel cost ($/hr)	Hiring rates ($/hr)	Unit rate ($/unit)	Total
1	2	3	4	5	6	7	8	9	10
EARTHWORKS									
1. Top soil									
1 bulldozer	cu.m	38	19	245	245	11	100	2.90	2.92
2. Cut & Fill									
1 bulldozer	cu.m	33	19	394	394	11	100	3.37	
1 wheel-roller	cu.m	122	21	107	394	12	50	1.62	4.99
3. Sub-grade finish									
1 grader	cu.m	80	17	154	154	10	100	1.38	
1 wheel-roller	cu.m	122	21	101	154	12	50	.73	2.11

1	2	3	4	5	6	7	8	9	10
METAL COURSE									
1. Upper sub-base (AP40)									
3 Tip trucks	cu.m	60	57	55	55	34	15	2.45	
1 grader	cu.m	60	17	55	55	10	100	1.84	
1 roller	cu.m	60	21	55	55	12	50	1.04	
1 Water truck	cu.m	60	19	55	55	11	10	.36	5.69
2. Sub-base (AP 60)									
3 Tip trucks	cu.m	60	57	88	88	34	15	2.45	
1 grader	cu.m	60	17	88	88	10	100	1.84	
1 roller	cu.m	60	21	88	88	12	50	1.04	
1 Water truck	cu.m	60	19	88	88	11	10	.36	5.69
3. Lower sub-base (silty sand)									
4 Tip trucks	cu.m	110	76	18	18	45	15	2.19	
1 grader	cu.m	110	17	18	18	10	100	1.00	
1 roller	cu.m	110	21	18	18	12	50	.57	
1 Water truck	cu.m	110	19	18	18	11	10	.19	3.96

1	2	3	4	5	6	7	8	9	10
4. Base course (M/4) solid									
3 Tip trucks	cu.m	60	57	85	85	34	15	2.45	
1 grader	cu.m	60	17	85	85	10	100	1.84	
1 roller	cu.m	60	21	85	85	12	50	1.04	
1 Water truck	cu.m	60	19	85	85	11	10	.36	5.69
5.Surfacing									
3 Tip trucks	cu.m	44	57	21	21	34	15	3.34	
1 grader	cu.m	44	17	21	21	10	100	2.51	
1 roller	cu.m	44	21	21	21	12	50	1.42	
1 Water truck	cu.m	44	19	21	21	11	10	.48	7.75
NCRETE PAVING									
1 Concrete finisher	cu.m	15	38	416	416	23	150	11.51	
2 Concrete vibrator	cu.m	15	8	416	416	5	5	.64	
2 Concrete saws	cu.m	15	8	208	208	5	7	.76	
1 Compressor	cu.m	15	14.17	208	208	9	95	6.90	
1 Transit-mix truck	cu.m	15	19	416	416	11	25	4.85	24.65

Table B 6.1: Flexible Pavement Construction Cost Estimate of Alternative (A) for New Zealand Road Project.

Description	Unit	Quantity	PERCENTAGE OF TOTAL: LABOUR	MATERIAL	EQUIP/TOOLS	O/H	UNIT RATES ($/Unit)	Amount ($)
EARTHWORKS								
1.Top soil	cu.m	9400	29%	0%	66%	5%	3.56	33447
2.Cut & Fill	cu.m	13000	43%	0%	52%	5%	7.09	92123
3. Subgrade surface finish	cu.m	12300	43%	0%	52%	5%	2.97	36565
METAL COURSE								
1. Upper sub-base (AP 40)	cu.m	3285	28%	23%	44%	5%	11.21	36837
2. Lower sub-base (Silty sand)	cu.m	2010	14.5%	54%	26.5%	5%	13.27	26670
BASE COURSE								
M/4 (solid)	cu.m	5110	30%	29%	36%	5%	13.67	69858
SURFACING								
Chip seal (thickness 25 mm)	sq.m	36500	1%	92%	2%	5%	7.35	268275
							Total =	$563,776

Table B 6.2: Flexible Pavement Construction Cost Estimates of Alternative (B) for New Zealand Road Project.

Description	Unit	Quantity	PERCENTAGE OF TOTAL				UNIT RATES ($/Unit)	Amount ($)
			LABOUR	MATERIAL	EQUIP/TOOLS	O/H		
EARTHWORKS								
1.Top soil	cu.m	9400	29%	0%	66%	5%	3.56	33447
2.Cut & Fill	cu.m	13000	43%	0%	52%	5%	7.09	92123
3. Subgrade surface finish	cu.m	12300	43%	0%	52%	5%	2.97	36565
METAL COURSE								
Sub-base (AP 60)	cu.m	5300	30%	18%	47%	5%	10.47	55482
BASE COURSE								
M/4 (solid)	cu.m	5110	30%	29%	36%	5%	13.67	69858
SURFACING								
Chip seal (thickness 25 mm)	sq.m	36500	1%	92%	2%	5%	7.35	268275
							Total =	555751

Table B 6.3: Rigid Pavement Construction Cost of Alternative (C) for New Zealand Road Project.

Description	Unit	Quantity	PERCENTAGE OF TOTAL				UNIT RATES ($/Unit)	Amount ($)
			LABOUR	MATERIAL	EQUIP/TOOLS	O/H		
EARTHWORKS								
1.Top soil	cu.m	9400	29%	0%	66%	5%	3.56	33447
2.Cut & Fill	cu.m	13000	43%	0%	52%	5%	7.09	92123
3. Subgrade surface finish	cu.m	12300	43%	0%	52%	5%	2.97	36565
METAL COURSE								
1. Upper sub-base (AP 40)	cu.m	3650	28%	23%	44%	5%	11.21	40930
2. Lower sub-base (Silty sand)	cu.m	2555	14.5%	54%	26.5%	5%	13.27	33902
BASE COURSE								
M/4 (solid)	cu.m	3833	30%	29%	36%	5%	13.67	52401
SURFACING								
Concrete pavement (Reinf. concrete 30 MPa) (thickness 160 mm)	cu.m	5840	4%	82%	9%	5%	261.41	1526640
						Total =		$1,816,008

Table B 6.4: Rigid Pavement Construction Cost of Alternative (D) for New Zealand Road Project.

Description	Unit	Quantity	PERCENTAGE OF TOTAL LABOUR	MATERIAL	EQUIP/TOOLS	O/H	UNIT RATES ($/Unit)	Amount ($)
EARTHWORKS								
1.Top soil	cu.m	9400	29%	0%	66%	5%	3.56	33447
2.Cut & Fill	cu.m	13000	43%	0%	52%	5%	7.09	92123
3. Subgrade surface finish	cu.m	12300	43%	0%	52%	5%	2.97	36565
METAL COURSE								
Sub-base (AP 60)	cu.m	6205	30%	18%	47%	5%	10.47	64956
BASE COURSE								
M/4 (solid)	cu.m	3833	30%	29%	36%	5%	13.67	52401
SURFACING								
Asphaltic plain concrete 20MPa (thickness 170 mm)	cu.m	6210	6%	77%	12%	5%	186.47	1157961
						Total =		$1,437,453

Table B 7.0: Table Giving Maintenance Unit Costs Data for New Zealand Road Project.

Cost Per Application in New Zealand Dollars						
		Percentage of Total				
Maintenance Operation	Unit	Labour	Equipment	Materials	Overhead	Total Unit cost
1 PATCHING	sq.m	60%	20%	15%	5%	$40.50
2 RESEALING	sq.m	10%	30%	50%	10%	$5.50
3 OVERLAY	sq.m	20%	20%	55%	5%	$9.00
4 RECONSTRUCTION	km	10%	20%	60%	10%	Varies
5 ROUTINE MAINTENANCE	km	55%	20%	20%	5%	$6,000.00

Table B 7.1: Maintenance Cost Estimates of Flexible Pavement, Discounted at 10% with 20 years for New zealand Road Alternative (A).

ITEM	MAINTENANCE OPERATION	UNIT	QUANTITY	INTERVAL (Years)	% TREATED	COST $/unit	PVF	PV
1	PATCHING	SQ.M	36500	2	10%	40.50	3.905	577321
2	RESEALING	SQ.M	36500	10	50%	5.50	.386	38699
3	OVERLAY	SQ.M	36500	16	100%	9.00	.218	71491
4	RECONSTRUCTION	KM	5	20	20%	112755	.149	16760
5	ROUTINE MAINTENANCE	KM	5	1	100%	6000.00	8.514	255407
						Total cost =		$959,678

Table B 7.2: Maintenance Cost Estimates of Flexible Pavement, Discounted at 10% with 20 years Life, for New Zealand Road Alternative (B).

ITEM	MAINTENANCE OPERATION	UNIT	QUANTITY	INTERVAL (Years)	% TREATED	COST $/unit	PVF	PV
1	PATCHING	SQ.M	36500	2	10%	40.50	3.905	577321
2	RESEALING	SQ.M	36500	10	50%	5.50	.386	38699
3	OVERLAY	SQ.M	36500	16	100%	9.00	.218	71491
4	RECONSTRUCTION	KM	5	20	20%	111150	.149	16522
5	ROUTINE MAINTENANCE	KM	5	1	100%	6000.00	8.514	255407
						Total cost =		$959,440

Table B 7.3: Maintenance Cost of Rigid Pavement, Discounted at 10% with 40 years Life, for New Zealand Road Alternative (C).

ITEM	MAINTENANCE OPERATION	UNIT	QUANTITY	INTERVAL (Years)	% TREATED	COST $/unit	PVF	PV
1	RETEXTURING	sq.m	36500	16	100%	3.00	.265	29017
2	SURFACE PATCHING	sq.m	36500	6	.5%	161.00	1.254	36850
3	CRACK STITCHING	m	70	10	100%	268.00	.614	11511
4	BAY REPLACEMENT	sq.m	550	10	100%	161	.614	54333
9								
5	JOINT REPLACEMENT							
	Transverse	m	1450	10	10%	268	.614	23844
	Longitudinal	m	250	10	100%	268	.614	41111
6	JOINT SEALING							
	Transverse	m	1450	8	100%	4	.833	4832
	Longitudinal	m	5000	12	100%	4	.453	9050
7	RECONSTRUCTION	km	5	40	20%	363202	.022	8025
8	ROUTINE MAINTENANCE	km	5	1	100%	6000	9.779	293372
								$511,944

Table B 7.4: Maintenance Cost of Rigid Pavement, Discounted at 10% with 40 years Life, for New Zealand Road Alternative (D).

ITEM	MAINTENANCE OPERATION	UNIT	QUANTITY	INTERVAL (Years)	PERCENTAGE TREATED	COST $/unit	PVF	PV
1	RETEXTURING	sq.m	36500	10	100%	4.00	.614	89584
2	SURFACE PATCHING	sq.m	36500	4	.5%	268.00	2.107	103058
3	CRACK STITCHING	m	140	10	100%	400.00	.614	34361
4	BAY REPLACEMENT	sq.m	1100	10	100%	215.00	.614	145114
5	JOINT REPLACEMENT							
	Transverse	m	1450	10	20%	535	.614	95199
	Longitudinal	m	500	10	100%	535	.614	164135
6	JOINT SEALING							
	Transverse	m	1450	4	100%	7	2.107	20470
	Longitudinal	m	5000	6	100%	7	1.254	42014
7	RECONSTRUCTION	km	5	40	20%	287491	.022	6352
8	ROUTINE MAINTENANCE	km	5	1	100%	6000	9.779	293372
					Total cost =			$993,660

Vehicle fleet characteristics nd unit costs for New Zealand roads.
All costs used n this analysi are in New Zealand dollars.

Table B 8: Economic Costs and Vehiile Groups for New Zealand.

ECONOMIC COSTS		S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
New vehicle (cost/vehicle)	¦	15510	15510	15510	36080	36080	111155
Tyre Labour (Cost/tyre)	¦	138	138	138	248	248	451
Maint. Labour (Cost/Labour-H)	¦	30	30	30	30	30	30
Crew-Time (Cost/crew-H)	¦	9	9	11	15	15	22
Annual Overhead Costs (Total)	¦10%	1547	1547	1801	6341	6341	18259
Annual interest rate %	¦	10	10	10	10	10	10

Table B 9: Vehicle Utilization a d Vehicle Groups for New Zealand.

VEHICLE UTILIZATION	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
Annual hours driven	1800	1800	1800	1800	1800	1800
Annual kilometres driven	14000	14000	20000	25000	25000	35000
Number of tyres/vehicle	4	4	4	6	6	10
Hourly utilization ratio	1	1	1	1	1	1
Vehicle service life (Years)	20	20	20	20	20	20

Table B 10: Vehicle Groups and Their Description for New Zealand.

VEHICLE DESCRIPTION	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
Vehicle type	1	2	4	6	7	8
Fuel type	Petrol	Petrol	Petrol	Petrol	Diesel	Diesel
Driving power (metric HP)	30	70	42	80	90	190
Axle type:						
Axle no.1	1	1	1	1	1	1
Axle no.2	1	1	1	2	2	2
Axle no.3						2

Table B 11: raffic Volumes and Growth Characteristics for New Zealand Project.

BASE YEAR	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK	TOTAL
Daily Traffic (ADT)	425	425	80	2	20	253	1205
Annual Traffic Growth (%)	2	2	2	2	2	2	

Table B 12: Table used in Calculating the Quantities of Resources Consumed per Veh-km for New Zealand Project.

COSTS	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
New vehicle (NV)	15510	15510	15510	36080	36080	111155
Tyres	193	193	275	509	509	928
Fuel	980.27	2287.30	1378.91	2614.05	1890.34	4005.40
Repairs & Maintenance	743	743	743	1040	1040	1040
Annual Overhead Costs	1547	1547	1801	6341	6341	18259
Depreciation	1329	1329	1329	3093	3093	9528
Total Costs less NV ($/km) =	.34	.44	.28	.68	.51	.96
Vehicle Operating Costs (VOC) =	$2,036,204	$2,591,690	$442,081	$33,992	$257,466	$8,541,197

Total Vehicle Operating Costs per year (TVOC/yr) $13,902,631

Depreciation (D) is calculated as follows:

$$D = \frac{\text{Year digit x Amount to be depreciated}}{\text{Sum of digits}}$$

A minimum salavage value of 10% of the initial cost is adopted for all vehicle types in this analysis.

Vehicle Resource Consumption:

1. FUEL CONSUMPTION

The rates of common fuel consumption can be based on the following:

(i) Gasoline, Gallons/ho0.11 x horsepower x load factor

(ii) Diesel fuel, Gallons0.06 x horsepower x load factor

For paved roads , Load factor =0.039

2. TYRE WEAR

Typical tyre life:

1. Cars and Utilities have 40000 km life
2. Trucks have 3500hr life

3. MAINTENANCE PARTS & LABOUR

Labour hours are related to parts requirements and, in some cases, to roughness. In New Zealand labour hours for Cars and Utilities is are taken on the average to be 25 hrs per annum. For Trucks and Buses 35 labour hours are taken.

Table B 13: The Table Used in Calculating Vehicle Operating Costs for New Zealand Road Project, Discounted at 10 %. for 20 and 40 Design Periods.

Year of Analysis	Actual VOC	PVF disc. = 10%	Discounted VOC	Total
1	13902631	.909	12638755	
2	17433229	.826	14407627	
3	20778532	.751	15611219	
4	23937378	.683	16349551	
5	28115291	.621	17457384	
6	29698255	.564	16763891	
7	32299124	.513	16574558	
8	34714698	.467	16194663	
9	36944999	.424	15668286	
10	38988799	.386	15031870	
11	40847096	.350	14316658	
12	42519397	.319	13547990	
13	44006173	.290	12747021	
14	45306745	.263	11930682	
15	46421769	.239	11113002	
16	47350568	.218	10304863	
17	48117853	.198	9519861	
18	48651795	.180	8750453	
19	49023546	.164	8015742	
20	49209095	.149	7314618	$264,258,694
21	13902631	.135	1878670	=============
22	17433229	.123	2141602	
23	20778532	.112	2320508	
24	23937378	.102	2430257	
25	28115291	.092	2594929	
26	29698255	.084	2491846	
27	32299124	.076	2463702	
28	34714698	.069	2407233	
29	36944999	.063	2328991	
30	38988799	.057	2234392	
31	40847096	.052	2128080	
32	42519397	.047	2013822	
33	44006173	.043	1894763	
34	45306745	.039	1773420	
35	46421769	.036	1651877	
36	47350568	.032	1531752	
37	48117853	.029	1415067	
38	48651795	.027	1300699	
39	49023546	.024	1191489	
40	49209095	.022	1087271	$303,539,065
				=============

APPENDIX C

The information included in this appendix illustrates the data used in analysing the Kenya road project together with the results that were obtained from the analyses. The information presented in the tables in this appendix show the input and output from the project cost analysis following the method of analysis set out in chapter 4.

Table C 1: List of Cost Data Estimates for Various Components Used to Calculate Costs for Kenyan Roads.

Item	Descriptions	Unit	Unit Costs (KSHS./Unit)
1	Crusher run	cu.m	260
2	Murram	cu.m	147
3	Hydrated lime	kg	1.25
4	Ordinary Portland cement	kg	1.6
5	Triple surface seal	sq.m	150
6	8 ton wheeled roller	hr	260
7	Cat D6 bulldozer with ripper	hr	720
8	Cat D8 bulldozer	hr	690
9	Tractor/trailor (3 cu.m loose), 85hp	hr	460
10	125 H.P Grader	hr	580
11	8 ton tipper truck, 4 cu. m, 100hp	hr	250
12	Grade formation	sq.m	10
13	100mm Water-bound macdam	sq.m	30
14	25mm Bitumen double seal	sq.m	90
15	38mm Premix bitumenous surfacing	sq.m	180
16	Unskilled labour	hr	8
17	Skilled labour	hr	9
18	Diesel fuel	litre	6.764
19	Petrol fuel	litre	10
20	Engine oil	litre	60
21	Wheel-barrow (.065 cu.m)	hr	.25
22	Water truck, 4.5cu.m	hr	140

Table C 2: Table Used to Calculate the Activities Times with their Labour Costs Including the Construction Methods Used for Kenyan Roads.

Descriptions.	Method	Input	Input Number	Units	Prod. (QTY/Unit)	Duration (Hours)	Tools Cost 2.5%x(9) (KShs/QTY)	Labour Cost (KShs./QTY)	Total (KShs/QTY)
1	2	3	4	5	6	7	8	9	10
I. CONSTRUCTION ACTIVITIES:									
ACTIVITY 1:	L-I:	Foreman	1	hr		83		.015	
CLEARING		Worker	10	hr	60	83		.133	.148
Quantity:		Tools		hr		83	.0037		
50000 sq.m									
	C-I:	Bulldozer D6	1	hr	1200	42			
		Operator	1	hr		42		.008	
		worker	1	hr		42		.007	.015
ACTIVITY 2:	L-I:	Foreman	1	hr		31		.023	
GRUBBING &		worker	20	hr	20	31		.400	.423
STRIPPING		Tools		hr		31	.0106		
Quantity:									
12500 sq.m	C-I:	Bulldozer D8	1	hr	900	14			

1	2	3	4	5	6	7	8	9	10
		Operator	1	hr		14		.003	
		Worker	1	hr		14		.002	.005
		Tools		hr		14			
ACTIVITY 3:	L-I:	Foreman	1	hr		355		.200	
(i) EXCAVATION,		Worker	80	hr	.563	355		14.210	
Cut & Fill		Driver (w/b)	57	hr		354		10.101	24.5
(firm soil & throwing		Wheel-barrow (wb)	57	hr	.792	354			
distance 0-4 m and hauling		Tools (+ wb)		hr		354	.6128		
distance 100m									
	C-I:	Bulldozer D8	1	hr	136	131			
Quantity:		Roller	1	hr	122	131			
16000 cu.m		Operators	2	hr		131		.148	
		Workers	2	hr		131		.131	
		Foreman	1	hr		131		.066	.344
(ii) Spreading									
	L-I:	Workers	30	hr	1.5	356		5.333	
		Roller	1	hr	122	356			
		Operator	1	hr		356		.200	
		Foreman	1	hr		356		.200	5.733
		Tools		hr		356	.1433		

1	2	3	4	5	6	7	8	9	10
ACTIVITY 4:									
(i) GRAVELLING				hr					
(Murram 150mm thick, lead 2 km)	L-I:	Tipper Truck	2	hr	21.5	131			
		Driver (T/truck)	1	hr		131			
Quantity:		Workers	30	hr	1.433	131		5.583	
		Foreman	1	hr		131		.209	5.792
5625 cu.m/loose		Roller	1	hr	118	131			
		Water truck	1	hr		131			
		Driver (W/truck)	1	hr		131			
		Operator (roller)	1	hr		131			
		Tools		hr		131	.1448		
	C-I:	Tipper truck	6	hr	21.5	49			
		Grader	1	hr	115	49			
		Roller	1	hr	118	49			
		Water truck	1	hr	11	49			
		Foreman	1	hr		49		.078	
		Operator (roller)	1	hr		49		.078	
		Operator (grader)	1	hr		49		.078	
		Drivers (T/trucks)	6	hr		49		.470	
		Workers	2	hr		49		.139	.843

1	2	3	4	5	6	7	8	9	10
(ii) GRAVELLING	L-I:	Tipper truck	2	hr	23	91			
(Macadam Construction)		Drivers (T/truck)	1	hr		91			
		Workers	40	hr	1	91		8.000	
(100mm thick Water-bound macadam,		Foreman	1	hr		91		.225	8.225
lead 2km work includes spreading		Roller	1	hr	60	91			
and compaction)		Water truck	1	hr	60	91			
		Driver (W/truck)	1	hr		91			
Quantity:		Tools		hr		91	.206		
3650 cu.m solid		Operator (roller)	1	hr		91			
	C-I:	Tipper truck	3	hr	23	61			
		Grader	1	hr	60	61			
		Roller	1	hr	60	61			
		Water truck	1	hr	60	61			
		Foreman	1	hr		61		.150	
		Operator (roller)	1	hr		61		.150	
		Operator (grader)	1	hr		61		.150	
		Drivers (T/trucks)	3	hr		61		.450	
		Workers	2	hr		61		.267	1.167

1	2	3	4	5	6	7	8	9	10
5. METAL COURSE									
(i) Sub-base (Lime+Murram)	C-I:	Tipper truck	6	hr	21.5	35			
		Grader	1	hr	115	70			
Quantity:		Roller	1	hr	118	35			
4015 cu.m including 10% of		Water truck	1	hr	115	35			
lime by volume of soil.		Foreman	1	hr		70		.157	
This process is repeated		Drivers	7	hr		35		.548	
twice		Operators	2	hr		70		.313	
		Workers	2	hr		70		.278	1.30
(iii) Base (Crusher run, 130mm thick)	C-I:	Tipper truck	3	hr	60	79			
		Grader	1	hr	60	79			
Quantity:		Roller	1	hr	60	79			
4745 cu.m solid		Water truck	1	hr	60	79			
		Foreman	1	hr		79		.150	
		Drivers	4	hr		79		.600	
		Operators	2	hr		79		.300	
		Workers	2	hr		79		.267	1.32

1	2	3	4	5	6	7	8	9	10
180mm Ditto	C-I:	Tipper truck	3	hr	60	110			
		Grader	1	hr	60	110			
Quantity:		Roller	1	hr	60	110			
6570 cu.m solid		Water truck	1	hr	60	110			
		Foreman	1	hr		110		.150	
		Drivers	4	hr		110		.600	
		Operators	2	hr		110		.300	
		Workers	2	hr		110		.267	1.32
SURFACING:									
(i) Asphalt 25mm tripple seal	C-I:	Tipper truck	3	hr	44	21			
		Grader	1	hr	44	21			
Quantity:		Roller	1	hr	44	21			
920 cu.m solid		Foreman	1	hr		21		.205	
		Drivers	3	hr		21		.614	
		Operators	2	hr		21		.409	
		Workers	2	hr		21		.364	1.59
(ii) 25mm bitumen double seal	C-I:	Tipper truck	3	hr	44	21			
		Grader	1	hr	44	21			
Quantity:		Roller	1	hr	44	21			
920 cu.m solid		Foreman	1	hr		21		.205	
		Drivers	3	hr		21		.614	
		Operators	2	hr		21		.409	
		Workers	2	hr		21		.364	1.59

1	2	3	4	5	6	7	8	9	10
II. MAINTENANCE ACTIVITIES:									
(b) Murram pavement									
ACTIVITY 1:									
REGRADING:	C-I:	Grader	1	hr	.84	4.2			
		Roller	1	hr	.86	17			
Quantity:		Foreman	1	hr		17		30.508	
5 km.		Operator	2	hr		17		61.017	
50mm loose material to be		Workers	1	hr		17		27.119	118.6
compacted.									
ACTIVITY 2:									
REGRAVELLING:	C-I:	Tipper Truck	6	hr	21.5	17.4			
		Grader	1	hr	115	17.4			
Quantity:		Roller	1	hr	118	17.4			
2000 cu.m		Foreman	1	hr		17.4		.078	
		Drivers	6	hr		17.4		.470	
ACTIVITY 3:		Operators	2	hr		17.4		.157	
Same as constrution estimates.		Workers	2	hr		17.4		.139	.84
(a) Macadam Pavement									
REGRADING:	C-I:	Grader truck	1	hr	60	16.7			
Quantity:		Roller	1	hr	60	16.7			
1000 cu.m		Foreman	1	hr		16.7		.150	
		Operators	2	hr		16.7		.300	
		Workers	1	hr		16.7		.133	.58

Table C 3: Table for Calculating Equipment Cost Estimates Including Operators for the Individual Activities of Kenyan Road Project.

Description	Units	TechOutput		EQUIPMENT			Fuel	Hiring	Unit cost	Total
				Fuel Consumed	Usage time	Required time	cost	rates		
			Unit/Hr	(L/Hr)	(Hrs)	(Hrs)	(Ksh/Hr)	(Ksh/Hr)	(Ksh/Unit)	(Ksh/Unit)
1	2	3	4	5	6	7	8	9	10	11
1. CLEARING (medium bush)										
		C-I:								
Bulldozer D6	sq.m		1200	10.395	42	42	70	720	.66	.66
2. GRUBBING STRIPPING										
		C-I:								
Bulldozer D8	cu.m		900	21.357	14	14	144	690	.93	.93
3. EXCAVATION										
CUT & FILL										
		C-I:								
Bulldozer D8	cu.m		136	21.357	118	131	144	690	6.72	
8 tonne Roller	cu.m		122	20.79	131	131	141	260	3.28	10.00
		L-I:								
8 tonne Roller	cu.m		122	20.79	131	356	141	260	6.93	6.93

1	2	3	4	5	6	7	8	9	10	11
4.GRAVELLING										
(Natural gravel-Murram)		C-I:								
Tipper trucks	cu.m		22	113.4	262	49	767	250	37.85	
Grader	cu.m		115	23.625	49	49	160	580	6.43	
8 tonne Roller	cu.m		118	20.79	48	49	141	260	3.45	
Water truck	cu.m		115	18.9	49	49	128	140	2.33	50.06
		L-I:								
Tipper trucks	cu.m		43	37.8	131	131	256	250	11.76	
8 tonne roller	cu.m		118	20.79	48	131	141	260	7.24	
Water truck	cu.m		118	18.9	48	131	128	140	4.34	23.34
4 (a) GRAVELLING										
(Macadam Construction)										
		C-I:								
Tip trucks	cu.m		69	94.5	53	61	639	250	13.43	
Grader	cu.m		60	23.625	61	61	160	580	12.33	
Roller	cu.m		60	20.79	61	61	141	260	6.68	32.44
		L-I:								
Tipper trucks	cu.m		46	37.8	79	91	256	250	11.81	
Roller	cu.m		60	20.79		91	141	260	6.50	
Water truck	cu.m		60	18.9	79	91	128	140	6.27	24.58

1	2	3	4	5	6	7	8	9	10	11
PAVED ROAD										
5. Sub-base										
(Lime/cement + Murram)		C-I:								
Tip trucks	cu.m		129	113.4	31	35	767	250	8.12	
Grader	cu.m		115	23.625	35	70	160	580	11.48	
Roller	cu.m		118	20.79	34	35	141	260	3.45	
Water tank	cu.m		115	18.9	35	35	128	140	2.33	25.38
6. Base										
(Crusher-run 130mm thick)		C-I:								
Tip trucks	cu.m		60	56.7	79	79	384	250	10.56	
Grader	cu.m		60	23.625	79	79	160	580	12.33	
Roller	cu.m		60	20.79	79	79	141	260	6.68	
Water tank	cu.m		60	18.9	79	79	128	140	4.46	34.03
Ditto										
(Crusher-run 180mm thick)		C-I:								
Tip trucks	cu.m		60	56.7	110	110	384	250	10.56	

1	2	3	4	5	6	7	8	9	10	11
Grader	cu.m		60	23.625	110	110	160	580	12.33	
Roller	cu.m		60	20.79	110	110	141	260	6.68	
Water tank	cu.m		60	18.9	110	110	128	140	4.46	34.03
7.Surfacing										
(25mm tripple seal)		C-I:								
Tip trucks	cu.m		44	56.7	21	21	384	250	14.40	
Grader	cu.m		44	23.625	21	21	160	580	16.81	
Roller	cu.m		44	20.79	21	21	141	260	9.11	40.32
Ditto (25mm double seal)										
		C-I:								
Tip trucks	cu.m		44	56.7	21	21	384	250	14.40	
Grader	cu.m		44	23.625	21	21	160	580	16.81	
Roller	cu.m		44	20.79	21	21	141	260	9.11	40.32
MAINTENANCE ESTIMATES:										
UNSEALED ROADS:										
(a) Murram pavement										
1. REGRADING										
		C-I:								
Grader	km		.84	23.625	4.2	4.2	160	580	621	

1	2	3	4	5	6	7	8	9	10	11
Roller	km		.86	20.79	17	17	141	260	1358	1979
2. GRAVELLING										
		C-I:								
Tip trucks	cu.m		129	113.4	15.5	17.4	767	250	8.12	
Grader	cu.m		115	23.625	17.4	17.4	160	580	6.43	
Roller	cu.m		118	20.79	16.9	17.4	141	260	3.45	
Water truck	cu.m		115	18.9	17.4	17.4	128	140	2.33	20.34
(b) Macadam Pavement										
Regrading		C-I:								
Grader	cu.m		60	23.625	17	17	160	580	12.33	
Roller	cu.m		60	20.79	17	17	141	260	6.68	19.01

Key:

C-I = Capital Intensive

C-I = Labour Intensive

Kshs. = Kenya shillings

Table C 4.1: Natural Gravel Murram Pavement Construction Cost Estimates dor Kenyan Road Project Using Capital-intensive Method.

Description	Unit	QUANTITY	PERCENTAG OF TOTAL LABOUR	MATERIAL	EQUIPMENT	O/H	UNIT RATES (Ksh/unit)	Amount (Ksh.)
1. CLEARING	sq.m	50000	2%	0%	93%	5%	.70	34979
2. GRUBBING & STRIPPING	cu.m	12500	1%	0%	94%	5%	.98	12198
3. EXCAVATION (Cut & Fill)	cu.m	16000	3%	0%	92%	5%	10.71	171388
4. GRAVELLING	cu.m	5625	1%	70%	24%	5%	207.72	1168433
							Total cost	1386998

Table C 4.2: Natural Gravel Murram Pavement Construction Cost Estimates for Kenyan Road Project Calculated Using Labour-intensive Method.

Description	Unit	Quantity	PERCENTAGE OF TOTAL LABOUR	MATERIAL	EQUIP/TOOLS	O/H	UNIT RATES (Ksh/unit)	Amount (Ksh.)
1. CLEARING	sq.m	50000	93%	0%	2%	5%	.16	7982
2. GRUBBING & STRIPPING	cu.m	12500	93%	0%	2%	5%	.45	5684
3. EXCAVATION (Cut & Fill)	cu.m	16000	76%	0%	19%	5%	39.83	637229
4. GRAVELLING	cu.m	5625	3%	79%	13%	5%	185.09	1041141
								1692035

Table C 5.1: Macadam Pavement Construction Cost Estimate for Kenyan Roads Calculated Using Labour Construction Method.

Description	Unit	Quantity	PERCENTAGE OF TOTAL				UNIT RATES (Ksh/unit)	Amount (Ksh.)
			LABOUR	MATERIAL	EQUIP/TOOLS	O/H		
1. CLEARING	sq.m	50000	93%	0%	2%	5%	.16	7982
2. GRUBBING & STRIPPING	cu.m	12500	93%	0%	2%	5%	.45	5684
3. EXCAVATION (Cut & Fill)	cu.m	16000	76%	0%	19%	5%	39.83	637229
4. GRAVELLING (Macadam)	cu.m	3650	2%	86%	7%	5%	349.66	1276245
								1927140

Table C 5.2: Macadam Pavement Construction Cost Estimate for Kenyan Road Calculated Using Capital-intensive method.

Description	Unit	Quantity	PERCENTAGE OF TOTAL				UNIT RATES	Amount
			LABOUR	MATERIAL	EQUIP/TOOLS	O/H	(Ksh/unit)	(Ksh.)
1. CLEARING	sq.m	50000	2%	0%	93%	5%	.70	34979
2. GRUBBING & STRIPPING	cu.m	12500	1%	0%	94%	5%	.98	12198
3. EXCAVATION (Cut & Fill)	cu.m	16000	3%	0%	92%	5%	10.71	171388
4. GRAVELLING (Macadam)	cu.m	3650	1%	85%	9%	5%	349.97	1277388
								1495953

Table C 6.1: Design Detail of Alternative Pavement Type With Tripple Seal Surfacing for Kenyan Paved Roads

Layer	Material	Thickness
SURFACING	25mm tripple surface seal	25
BASE	Crusher run	130
SUB-BASE	Lime + murram	100

Table C 6.2: Design Detail of Alternative Pavement Type with Double Seal Surfacing for Kenyan Paved Roads

Layer	Material	Thickness
SURFACING	25mm Bitumen Double seal	50
BASE	Crusher run	180

Table C 7.1: Construction Cost Estimates of Kenyan Paved Road project with Tripple Surfacing Seal

Calculated Using Capital-intensive Method

Description	Unit	Quantity	PERCENTAGE OF TOTAL				UNIT RATES	Amount
			LABOUR	MATERIAL	EQUIP/TOOLS	O/H	(Ksh/unit)	(Ksh.)
1. CLEARING	sq.m	50000	2%	0%	93%	5%	.70	34979
2. GRUBBING & STRIPPING	cu.m	12500	1%	0%	94%	5%	.98	12198
3. EXCAVATION (Cut & Fill)	cu.m	16000	3%	0%	92%	5%	10.71	171388
4. SUB-BASE (Lime & Murram)	cu.m	4015	.4%	88%	6.6%	5%	387	1552838
5. BASE (130mm thick Crusher-run)	cu.m	4745	.4%	83.6%	11%	5%	310.11	1471489
6.SURFACING (25mm bitumen tripple seal)	cu.m	920	1%	74%	20%	5%	201.50	185383
								3428275

Table C 7.2: Construction Cost Estimates of Kenyan Paved Road Project with Double Surface Seal Calculated Using Capital-intensive Method

Description	Unit	Quantity	PERCENTAGE OF TOTAL				UNIT RATES	Amount
			LABOUR	MATERIAL	EQUIP/TOOLS	O/H	(Ksh/unit)	(Ksh.)
1. CLEARING	sq.m	50000	2%	0%	93%	5%	.70	34979
2. GRUBBING & STRIPPING	cu.m	12500	1%	0%	94%	5%	.98	12198
3. EXCAVATION (Cut & Fill)	cu.m	16000	3%	0%	92%	5%	10.71	171388
4. BASE (180mm thick Crusher-run)	cu.m	6570	.4%	83.6%	11%	5%	310.11	2037447
5.SURFACING (25mm bitumen double seal)	cu.m	920	1%	65%	29%	5%	138.07	127028
								2383039

Table C 8.1: Maintenance Cost of Unsealed Murram Pavement for Kenyan Road, Discounted at 15% with 20 years Design Period.

ITEM	MAINTENANCE OPERATION	UNIT	QUANTITY	FREQUENCY (Years)	PER CENT TREATED	COST Ksh./unit	PVF	PV (Kshs.)
1	REGRADING	km	5	.25	100%	7917.91	6.198	245385
2	REGRAVELLING	cu.m	2000	2	100%	20.34	2.850	115929
3	RESURFACING	cu.m	5625	10	80%	246.58	.308	273658
4	ROUTINE MAINTENANCE	km	5	1	100%	6934.99	6.259	217042
						Total cost =		852014

Table C 8.2: Maintenance Cost of Unsealed Macadam Pavement for Kenyan Road,
Discounted at 15% with 20 years Design Period.

ITEM	MAINTENANCE OPERATION	UNIT	QUANTITY	FREQUENCY (Years)	PER CENT TREATED	COST Ksh./unit	PVF	PV (Kshs.)
1	REGRADING	km	5	.5	100%	7603	6.198	235620
2	REGRAVELLING	cu.m	5625	5	30%	227	.867	99704
3	RESURFACING	cu.m	5625	20	100%	266	.061	91403
4	ROUTINE MAINTENANCE	km	5	1	100%	7480	6.259	234092
						Total cost =		660819

Table C 9.1: Maintenance Cost of Sealed Kenyan Road with a Tripple Surface Seal
Discounted at 15% with a 20 years Study Period.

ITEM	MAINTENANCE OPERATION	UNIT	QUANTITY	FREQUENCY (Years)	PER CENT TREATED	COST Ksh./unit	PVF	PV (Kshs.)
1	PATCHING	sq.m	36500	2	15%	300	2.850	4681481
2	RESEALING	sq.m	36500	10	100%	110	.308	1237764
3	OVERLAY	sq.m	36500	16	90%	180	.107	631891
4	RECONSTRUCTION	km	5	20	40%	685655	.061	83787
5	ROUTINE MAINTENANCE	km	5	1	100%	5000	6.259	156483
							Total Maintenance cost	6791407

Table C 9.2: Maintenance Cost of Sealed Kenyan Road with a Double Surface Seal Discounted at 15% with a 20 years Study Period.

ITEM	MAINTENANCE OPERATION	UNIT	QUANTITY	FREQUENCY (Years)	PER CENT TREATED	COST Ksh./unit	PVF	PV (Kshs.)
1	PATCHING	sq.m	36500	2	15%	300	2.850	4681481
2	RESEALING	sq.m	36500	10	100%	110	.308	1237764
3	OVERLAY	sq.m	36500	16	90%	180	.107	631891
4	RECONSTRUCTION	km	5	20	40%	476608	.061	58242
5	ROUTINE MAINTENANCE	km	5	1	100%	5000	6.259	156483
							Total Maintenance cost	6765862

KENYAN ROAD USER COST

A detailed approach of how road user costs are determined was given in section 6.4.4. This appendix gives the fleet characteristic and unit costs needed to determine the road user costs. It was mentioned earlier that user costs consist of travel time and vehicle operating costs. Only vehicle operating costs are considered for analysis in this study. The procedure used in calculating the vehicle operating costs (VOC) is as follows:

Step 1 Establish the Vehicle Economic Costs

To achieve this it is important to get the data needed for economic evaluation. The necessary data include the fixed and running costs of the vehicle groups, see table C10.

Step 2 Establish the Vehicle Utilization

This requires knowing the statistics of the vehicles using a particular road. Details of the statistical data necessary are given in table C11.

Step 3 Establish the Vehicle Characteristics

Some of the information necessary for this includes vehicle fuel type, gross weight of vehicle as well as its driving power. Details of the data required are given in table C12.

Step 4 Establish the Traffic Volume and Growth Characteristics

This data is important in getting the total vehicle operating cost. Tables C13 and C14 give the detailed data used in this analysis for the Kenyan road project.

Step 5 Calculate the Vehicle Operating Costs

Vehicle operating costs are determined from the quantities of resources consumed by applying user-specified unit costs, and by allowances for depreciation, interest, overheads and time values of delays.

The procedure is:

(i) Compute the resources consumed per vehicle/km by the group.

In this study the resources considered for analysis are:
(a) Fuel
(b) Tyre wear
(c) Maintenance parts
(d) Maintenance labour
(e) Depreciation
(f) Overheads

(ii) Multiply the vehicle/km cost by the section length and year's traffic to determine the total costs for each group, and for all groups. For the Kenyan road project the data used for the quantities of resources consumed is given in this appendix under the heading "Relationships for Vehicle Operating Costs Other Than Fuel", (ROBINSON, 1975).

RELATIONSHIPS FOR VEHICLE OPERATING COSTS OTHER THAN FUEL

1. Oil consumption

Paved roads:

Cars	1.2 litres/1000 km
Light vehicles	1.8 litres/1000 km
Trucks and buses	4.0 litres/1000 km

These figures are doubled on unpaved roads.

2. Spare parts consumption

Light vehicles

Paved roads, $2000 \leqslant R \leqslant 4230$ and all unpaved roads $2000 \leqslant R \leqslant 8000$:

$$\frac{PC}{VP} = (-2.03 + 0.0018R) \times K \times 10^{-11}$$

Paved roads, $4230 \leqslant R \leqslant 8000$:

$$\frac{PC}{VP} = (-5.50 + 0.00262R) \times K \times 10^{-11}$$

Trucks

Paved roads, $3370 \leqslant R \leqslant 7500$:

$$\frac{PC}{VP} = (-6.538 + 0.00316R - 0.000\,000\,21R^2) \times K \times 10^{-11}$$

Paved roads, $2000 \leqslant R \leqslant 3370$ and all unpaved roads, $R_{max} = 8000$:

$$\frac{PC}{VP} = (0.48 + 0.00037R) \times K \times 10^{-11}$$

Buses

Paved and unpaved roads, $2000 \leqslant R \leqslant 8000$

$$\frac{PC}{VP} = (0.67 + 0.0006R) \times K^{\frac{1}{2}} \times 10^{-11}$$

where:

PC	=	parts cost per kilometre
VP	=	cost of an equivalent new vehicle
K	=	total kilometres run to date
R	=	surface roughness (mm/km)

3. Maintenance labour hours

Light vehicles

$$LH = \frac{PC}{VP} (851-0.078R)$$

Trucks

$$LH = \frac{PC}{VP} (2975-0.078R)$$

Buses

$$LH = \frac{PC}{VP} (2640-0.078R)$$

where: LH = labour hours per kilometre

PC = parts cost per kilometre

K = total kilometres run to date

R = surface roughness (mm/km)

4. Tyre consumption

Light vehicles

Paved and unpaved roads, $2000 \leq R \leq 8000$

$$T = (-0.0601 + 0.0000764R) \times 10^{-3}$$

Trucks and buses

Paved roads, $5200 \leq R \leq 8000$

$$T = (0.071 + 0.0000135R) \times L \times 10^{-4}$$

Paved roads, $2000 \leq R \leq 5200$ and

all unpaved roads, $2000 \leq R \leq 8000$

$$T = (0.083 + 0.0000112R) \times L \times 10^{-4}$$

where: T = tyres per kilometre

R = surface roughness (mm/km)

L = weight of vehicle (tonne)

5 . Depreciation

Light vehicles

For vehicles one year old

$$D = 22$$

For vehicles greater than one year old

$$D = 20.46 + 7.80A, \quad D \leqslant 90$$

Trucks and buses

$$D = -50.71 + 64.28A^{\frac{1}{3}}, \quad D \leqslant 90$$

where: D = percentage depreciation

A = age of vehicle in years

6 . FUEL CONSUMPTION

The rates of common fuel consumption can be based on the following:

(i) Gasoline, Gallons/hour = 0.11 x horsepower x load factor

(ii) Diesel fuel, Gallons /hour = 0.06 x horsepower x load factor

(iii) Oil consumption:

For paved roads , fuel consumption factor =0.039

For unpaved road, fuel consumption factor = 0.08

Table C 10: Economic Costs and Vehicle Groups for Kenyan Roads.

ECONOMIC COSTS	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
New vehicle (cost/vehicle)	180000	320000	200000	400000	500000	1000000
Tyre Labour (Cost/tyre)	800	1000	1200	1500	1500	4000
Maint. Labour (Cost/Labour-H)	100	100	100	100	100	100
Crew-Time (Cost/crew-H)	20	20	25	25	30	50
Annual Overhead Costs @10%	18000	32000	20000	60000	75000	150000
Annual interest rate %	10	10	10	10	10	10

Key: S.CAR = Small Cars

M.CAR = Medium cars

UTILITY = Utility or Light Commercial Vehicles

LTRK.P = Light Truck Using Petrol (Medium Commercial Vehicle)

LTRK.D = Light Truck Using Diesel (Medium Commercial Vehicle)

H.TRCK = Heavy Truck (Heavy Commercial Vehicle)

Table C 11: Vehicle Utilization and Groups for Kenyan Roads.

VEHICLE UTILIZATION	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
Annual hours driven	1800	1800	1800	1800	1800	1800
Annual kilometres driven	14000	14000	20000	25000	25000	35000
Number of tyres/vehicle	4	4	4	6	6	10
Hourly utilization ratio	.6	.6	.8	.85	.85	.85
Vehicle service life (Years)	20	20	20	20	20	20

Table B 12: Vehicle Descriptions and Groups for Kenyan Roads

VEHICLE DESCRIPTION	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
Vehicle type	1	2	4	6	7	8
Fuel type	Petrol	Petrol	Petrol	Petrol	Diesel	Diesel
Driving power (metric HP)	30	70	42.2	80	89.67	190
Axle type:						
Axle no.1	1	1	1	1	1	1
Axle no.2	1	1	1	2	2	2
Axle no.3						2
Gross vehicle weight (TONS)	1.05	1.45	1.44	3.16	5.87	18.04

Table C 13: Traffic Volumes and Growth Characteristics for Kenyan Paved Roads.

BASE YEAR (Paved road)	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK	TOTAL
Daily Traffic (ADT)	335	335	58	15	14	123	880
Annual Traffic Growth (%)	6	6	6	6	6	6	

Table C 14: Traffic Volumes and Growth Characteristics for Kenyan Unpaved Roads.

BASE YEAR (Un aved road)	S.CAR	M.CAR	UTILI	LTRK.	LTRK.D	H.TRCK	TOTAL
Daily Traffic (ADT)	30	30	20	10	10	0	100
Annual Traffic Growth (%)	6	6	6	6	6	6	

Table B 15: Table showing the outcome of vehicle operating costs from the 13 th year of analysis onwards for Kenya unpaved roads.

Year COSTS (Unpaved roads)	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
New vehicle (NV)	180000	320000	200000	400000	500000	1000000
Tyres	.319	.169	.203	.071	.132	1.084
Fuel	1.688	3.748	1.737	2.522	1.965	3.126
Spare parts	.221	.393	.351	.270	.338	.945
Maintenance labour hours	.018	.018	.026	.100	.100	.140
Annual Overhead Costs (10%)	1.286	2.286	1.000	1.600	2.000	2.857
Depreciation	162000	288000	180000	360000	450000	900000
Total Costs less NV (Kshs/km) =	15.10	27.18	12.32	18.96	22.53	33.87
Vehicle Operating Costs (VOC) =	6343368	11417620	4926501	4740800	5633488	0

Total Vehicle Operating Costs per year (TVOC/yr) = 33061777

Table B 16: Table showing the outcome of vehicle operating costs in the first or service for Kenya paved road.

COSTS (Paved roads)	S.CAR	M.CAR	UTILITY	LTRK.P	LTRK.D	H.TRCK
New vehicle (NV)	180000	320000	200000	400000	500000	1000000
Tyres	.135	.169	.203	.055	.103	.841
Fuel	.825	1.829	.849	1.232	.960	1.530
Spare parts	.085	.151	.135	.159	.199	.557
Maintenance labour hours	.029	.029	.042	.109	.109	.153
Annual Overhead Costs (10%)	1.286	2.286	1.000	1.600	2.000	2.857
Depreciation TOTAL	21600	38400	24000	14280	17850	35700
Total Costs less NV (Kshs/km) =	3.90	7.21	3.43	3.73	4.08	6.96
Vehicle Operating Costs (VOC) =	18304040	33798544	3977241	1397548	1429676	29952837

Total Vehicle Operating Costs per year (TVOC/yr) = 88859886

A salvage value of 10% is adopted for Kenya roads.

What is important to note here is the TVOC/yr was determined every year for during the vehicle service life by taking into the venicle annual depreciation. These yearly costs were put in a tabulated form as shown in table B 16 both for paved and unpaved Kenya roads. Later these costs were discounted and summed up to get the VOC of road project for a given design life.

Table C 17: Vehicle Operating Cost for Kenyan Roads, Discounted at 15% with a 20 years Design Period.

Year	Present Value Factors of 15 % Discount rate	ROAD USER COST: Paved road: Actual	Paved road: Discounted at 15%	Unpaved road: Actual	Unpaved road: Discounted at 15%
1	.870	88859886	77269466	10463077	9098328
2	.756	136763828	103413102	14638177	11068565
3	.658	166672951	109590171	17174977	11292826
4	.572	193331978	110538186	19496717	11147311
5	.497	218017464	108393211	21687827	10782683
6	.432	241353873	104343940	23789687	10284938
7	.376	263699501	99134410	25825967	9708938
8	.327	285280946	93258847	27811677	9091687
9	.284	306266736	87060121	29766967	8461630
10	.247	327034317	80837882	31892627	7883370
11	.215	335853646	72189465	32574397	7001646
12	.187	345889956	64649306	32919957	6152975
13	.163	346102686	56251362	33061777	5373463
14	.141	346102686	48914228	33061777	4672577
15	.123	346102686	42534111	33061777	4063110
16	.107	346102686	36986184	33061777	3533139
17	.093	346102686	32161899	33061777	3072295
18	.081	346102686	27966869	33061777	2671561
19	.070	346102686	24319016	33061777	2323096
20	.061	346102686	21146971	33061777	2020084
		TOTAL	1400958747.026		139704221

Classn:

TOTAL LIFE CYCLE COST IN THE CONSTRUCTION INDUSTRY

V. Ssewanyana

ABSTRACT: An economic evaluation technique which takes into account initial and recurring costs of any project in the construction industry is presented. Bridge and road projects were analysed. The results indicate the usefulness of this technique as a decision-making tool and its application to projects in the construction industry.

Department of Civil Engineering, University of Canterbury, Master of Engineering Report, 1990.